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ROYAL AIRCRAFT ESTABLISHMENT

FARNBOROUGH, HANTS

TECHNICAL NOTE No: G.W.227

INVESTIGATION INTO THE PERFORMANCE OF A "REID" FORCED AIR BLAST RAMJET COMBUSTION CHAMBER ON A LOW PRESSURE COMBUSTION RIG

by

J.S.DRABBLE

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Investigation into the Performance of a "Reid" Forced Air Blast Ramjet Combustion Chamber on a Low Pressure Combustion Rig

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SUMMARY

This report contains an account of an investigation carried out with a 6" diameter "Reid" air blast ramjet burner at low inlet pressures on a coupled pipe test rig.

The results presented cover an operating range of from 16" Hg.abs. to 50" Hg.abs. at the burner inlet and show the effect of air blast injection pressure, combustion chamber inlet pressure and temperature, tailpipe length and tailpipe exit restriction on the combustion stability range and air specific impulse developed by the burner.

A full description of the test rig and a summary of the initial calibration of the rig and thrust measuring apparatus are included.

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1 Introduction

1.1 Since the initial development work on ramjet combustion chambers at R.A.E.[1,2] was carried out on sea level combustion rigs exhausting to atmospheric pressure and with the inlet air pressures in the region of $2\frac{1}{2}$ - $3\frac{1}{2}$ atmos. abs., and since, as is well known, burner performance deteriorates, as regards both stability range and combustion efficiency as the inlet pressure is decreased, the need arose for an investigation of burner performance under simulated altitude conditions.

1.2 To satisfy this requirement a coupled pipe rig equipped for thrust measurement was constructed, in which the ramjet exhaust gases were discharged into a cooled settling chamber which was maintained at a low pressure by exhauster pumps.

1.3 Initially the air supplied to the ramjet was drawn through a control valve from the atmosphere, thus limiting the test range to burner inlet pressures of 1 atmos. abs. or less. The rig was, however, subsequently modified by the installation of centrifugal compressors in the supply line to enable supply pressures up to $2\frac{1}{2}$ atmos. abs. to be obtained, thus bridging the gap between the operating ranges of the existing sea level combustion rigs and the original simulated altitude rig with atmospheric inlet.

2 The Aim and Scope of the Investigation

The experimental work reported herein was carried out to determine the performance at low inlet pressures of a 6" diameter "Reid" forced air blast burner, a combustion system which had previously been developed and calibrated on a sea level coupled pipe combustion rig.[2]

In particular an investigation was made of the effect on combustion stability range and air specific impulse of variation in the following parameters:-

(i) Air blast injection pressure
(ii) Burner Inlet Pressure
(iii) Burner Inlet Temperature
(iv) Tailpipe length
(v) Tailpipe exit area

All these tests were carried out with a Mark V Flight type burner (see Ref.2), since it was desired mainly to investigate the effect of low pressures on an existing design, rather than to improve the altitude performance by modification of the burner geometry.

The tailpipe exit area was reduced with a restrictor having a single radius profile and a parallel outlet.

3 Description of Test Rig

3.1 A schematic layout of the rig as it is at present is shown in Fig.1.

3.2 Air enters the rig, either from the centrifugal compressors or from atmosphere, and is controlled in pressure by means of a blow-off valve and a barrel throttle valve. It then passes through two electric heaters in series, a flame trap and a conical colander into the upstream section of the tunnel.

3.3 Thence it flows radially into the nozzle box, through a nozzle to the burner and tailpipe. The tailpipe gases exhaust into a water jacketed exhaust tunnel 24 inches in diameter where they are spray cooled, and then via an exhaust main in which is installed a tubular cooler, to the exhauster pumps.

3.4 The nozzle box, nozzle, burner and tailpipe assembly is mounted on rollers which centralise the sliding joints, thus enabling the leaks between adjacent sections to be kept to a minimum.

3.5 Fixed to the upstream end of the nozzle box is a push rod which operates the thrust measuring apparatus.[3] The pressure on the end faces of the sliding joints is equalised by pressure balance pipes, thus eliminating error in thrust measurement due to change in exhaust tunnel pressure.

3.6 All connections to the floating section are made via 36 inch lengths of flexible pipe hanging vertically in a tower above the burner. As the horizontal movement of the burner is not more than 0.020 inch the horizontal force component in the flexible pipes caused by this movement has been neglected.

3.7 The total temperature and total and static pressures at the burner inlet are measured by a suction pyrometer and a standard B.S.S. pitot-static point installed respectively upstream and downstream of the nozzle.

3.8 A large door on each side of the exhaust tunnel gives access to the burner and tailpipe and four $1\frac{1}{4}$ inches diameter quartz windows in each door, together with a 6 ins. diameter perspex window on the top of the tunnel opposite the end of the tailpipe, allow visual examination.

3.9 An R.A.E. high energy ignition system was used to ignite the ramjet in preference to a standard aircraft booster coil, as it was found that the higher energy release of the former facilitated ignition at low pressures.

3.10 The fuel system as installed provides two independent fuel supplies to the burner. Fuel flow is measured in the primary system by means of rotameters having a range of 0 - 600 lbs/hr. and in the secondary system by rotameters with a range of 20 - 1800 lbs/hr. Each system is supplied by a separate fuel pump, coarse control being effected by a bypass circuit and fine control by a needle valve. Volumetric flasks are installed for rotameter calibration.

3.11 A compressed air supply for the forced air blast atomisation is controlled by a third needle control valve.

3.12 Connections for measuring the pressure of the fuel and air blast are made as close to the burner as possible.

3.13 Manometer tubes are used to indicate the following pressures:- chamber inlet static and chamber inlet total, as measured by the pitot static tube for calculating the air mass flow; exhaust main static, pressure box static and downstream sliding joint static. When a tailpipe exit restrictor is used an additional manometer records the static pressure at the restrictor outlet.

4 <u>Rig Calibration</u>

4.1 As the air mass flow was to be calculated from a knowledge of the inlet total temperature, the total and the static pressures, a cold flow calibration was essential.

4.2 This calibration was made firstly to ensure that the velocity distribution over the measuring section was uniform and unaffected by the geometry of the burner; secondly, to ensure that the temperature distribution was uniform, and thirdly, to determine the flow discharge coefficient in the plane of the pitot-static point.

4.3 The method adopted consisted in traversing the chamber across two perpendicular diameters with the burner removed and then repeating the traverse with the burner in position.

4.4 After adjustment of the conical colander because of uneven distribution the results shown in Figs.2 to 4 were obtained. Figs.2 and 3 show the velocity distribution across the chamber inlet for two different velocities, and inlet pressures of 20 ins. Hg.abs. and 29 ins. Hg.abs. respectively. Fig.4 shows the velocity distribution at the chamber inlet with the burner and a 5 ft. tailpipe in position.

4.5 The results show that the velocity distribution is the same in all cases and does not vary appreciably across the section, and that the discharge coefficient is equal to 0.97.

4.6 Figs.5 and 6 show the temperature distribution at the chamber inlet for the two heaters used separately. The distribution with either heater in both the vertical and horizontal planes is satisfactory.

4.7 A cold burner pressure loss curve was taken for the "Reid" air blast burner. It agreed, to within 1½% with that previously obtained on the sea level rig.

4.8 When the thrust gear was installed a comparison was made between the exit momentum, calculated from the air mass flow and velocity, and the thrust as indicated by the thrust gear. In all cases the agreement was within 1½%, the majority of comparisons being within ½%.

5 General Procedure and Experimental Technique

5.1 In the course of the investigations many combinations of air blast pressure, chamber inlet pressure and temperature, tailpipe length and exit restrictor size were tested, and for each combination tried a stability curve was taken. In obtaining this curve, the rich and weak combustion extinction limits were determined and the main fuel flow plotted against pilot fuel flow at extinction, all the other variables being fixed for any one curve.

5.2 The following experimental procedure was adopted in obtaining a stability curve. After starting the exhauster pumps the inlet throttle valve was opened and air caused to flow through the rig by slowly opening the main exhaust valve. The air temperature was raised to approximately the required value, and the water for the cooling sprays and the tailpipe turned on. This latter operation automatically closed a switch inserted in the ramjet ignition circuit as a precautionary measure.

5.3 The high energy ignition system, which causes a regular discharge across the surface of an insulator from a centre electrode to the inside surface of the conical flame stabiliser was switched on. The ramjet pilot fuel flow was then slowly increased until ignition took place, when the igniter was switched off. The fuel flow was suitably set so that by opening the main exhaust valve sufficiently the ramjet exhaust became choked.

5.4 The chamber inlet pressure and temperature were then set to the required values by means of the inlet throttle valve and the heater controls, and held at these values for the duration of the test. Finally the fuel flow was increased using either the pilot or the main fuel control, until combustion extinction occurred, at which point readings were recorded of the total temperature, static pressure and total pressure minus static pressure at the combustion chamber inlet together with readings of the fuel flows. From these values the air mass flow and, if required, the air fuel ratio, were calculated. The weak extinction limit was then obtained in similar fashion and the whole procedure repeated at various pilot fuel flows.

5.5 Stability curves were obtained by repeating the technique for a series of combustion chamber inlet pressures, burner air blast pressures, tailpipe lengths and restrictor sizes.

5.6 From an inspection of the stability curves a value of pilot fuel flow was chosen, for particular inlet conditions, which gave a wide range of main fuel flow between rich and weak extinctions. With combustion initiated, inlet conditions held steady and the exhaust choked, the pilot fuel flow was set as chosen and the main fuel flow set at a value approaching that at weak extinction. The value of the thrust, as indicated on the thrust measuring apparatus, was noted, together with the static pressures at the combustion chamber inlet, tailpipe exit and in the pressure box, and the total pressure minus static pressure at the combustion chamber inlet. From these figures the Air Specific Impulse, S_A, was calculated and the value plotted against the air fuel ratio. The procedure was repeated for several increasing values of the main fuel flow until rich extinction was reached. The whole curve was repeated for a series of combustion chamber inlet pressures, burner air blast pressures, tailpipe lengths and restrictor sizes.

5.7 Throughout the tests the fuel used was Standard Aviation Kerosine to Specification D.ENG.R.D.2482 with a maximum of 1% oil added. Towards the end of the tests, for reasons briefly discussed in paragraph 7.4, the fuel was selected so as to maintain the vapour pressure, measured at 120°C, within close limits.

6 Summary of Results

6.1 Combustion tests with "Reid" flight type burner and a 5 ft tailpipe

6.11 Figs.7 to 11 show the stability curves obtained using air inlet pressures of 26, 23, 20, 18 and 16 ins. Hg.abs. respectively and an inlet temperature of 120°C.

6.12 The thrust was measured along a line of fixed pilot fuel flow, suitable, at a particular chamber inlet pressure, for all the air blast pressures. Figs.12 to 16 show the value of the air specific impulse, S_A, plotted against total air fuel ratio, illustrating the effect of air blast pressure, for chamber inlet static pressures of 26 to 18 ins. Hg.abs. and a chamber inlet total temperature of 120°C, the pilot fuel flows being as indicated on the graphs.

6.2 Combustion tests with "Reid" flight type burner and a 5 ft.$10\frac{1}{2}$ ins. tailpipe

6.21 Stability loops plotted as pilot fuel flow against main fuel flow, using various air blast pressures, are presented in Figs.17 to 20, for chamber inlet static pressures of 50, 26, 20 and 16 ins. Hg.abs. respectively and a chamber inlet total temperature of 120°C.

6.22 Figs.21 to 24 show the variation in air specific impulse along lines of constant pilot fuel flow at various air blast pressures and chamber inlet static pressures of 50, 26, 20 and 16 ins. Hg.abs. respectively.

6.23 A chamber inlet total temperature of 75°C was used for further tests, the results of which are shown in Figs.25 to 27 in which are plotted stability loops showing pilot fuel flow at chamber inlet pressures of 26, 20 and 18 ins. Hg.abs. respectively for various air blast pressures, as indicated.

6.24 The values of air specific impulse versus air fuel ratio at chamber inlet static pressure of 26 and 20 ins. Hg.abs. and an inlet total temperature of 75°C are plotted in Figs.28 and 29 showing the effect of two air blast pressures.

6.25 The effect that chamber inlet temperature has on stability is shown in Fig.30 where the stability curves obtained at a chamber inlet pressure of 26 ins. Hg.abs. and air blast pressure of 50 lbs/in^2 above chamber pressure using a 5 ft.10$\frac{1}{2}$ ins. tailpipe at three inlet temperatures are plotted. The temperature effect is very marked, both rich and weak extinction limits, and particularly the former, being weakened by an increase in temperature.

6.3 <u>Combustion tests using tailpipes with exit restrictors</u>

6.31 <u>15% exit restrictor</u>

Similar stability curves were obtained as with parallel tailpipes, and Fig.31 shows pilot fuel flow versus main fuel flow at 26 ins. Hg.abs. inlet static pressure for two air blast pressures when using a 5 ft.10$\frac{1}{2}$ ins. tailpipe.

6.32 Tailpipe lengths quoted whilst using a restrictor include the length of the restrictor.

6.33 The curves of air specific impulse versus air-fuel ratio for a 5 ft.10$\frac{1}{2}$ ins. tailpipe at 26 ins. Hg.abs. and air blast pressures of 40 and 50 lbs/in^2 above chamber pressure are shown in Figs.32 and 33 respectively.

6.34 <u>30% exit restrictor</u>

An attempt was made, using a 5 ft.10$\frac{1}{2}$ ins. tailpipe and 30% restrictor, to obtain a stability loop, but it was not found possible to increase the main fuel flow above 200 lbs/hr., although attempts were made at elevated temperatures at 26 ins. Hg.abs. inlet static pressure.

6.35 With a tailpipe length of 4 ft.10$\frac{1}{2}$ ins. a small stability loop was obtained at 120°C and an air blast pressure of 30 lbs/in^2 above chamber pressure. Similarly a curve was obtained with a tailpipe length of 4 ft.3 ins., both of which are shown in Fig.34.

6.36 The effect of air blast pressure on the stability when using a 4 ft.3 ins. tailpipe is shown in Figs.35 and 36 for chamber inlet static pressures of 26 and 20 ins. Hg.abs. respectively.

6.37 The values of the air specific impulse obtained while using a 4 ft.3 ins. tailpipe with a 30% exit restrictor are shown plotted against air-fuel ratio for two air blast pressures and at chamber inlet pressures of 26 and 20 ins. Hg.abs. in Figs.37 and 38 respectively.

6.38 For comparison between the performance of the burner when using a 5 ft.$10\frac{1}{2}$ ins. parallel tailpipe and a 5 ft.$10\frac{1}{2}$ ins. tailpipe with a 15% restrictor, the Figs.39 and 40 show the stability for both cases. In both instances the chamber inlet conditions are 26 ins. Hg.abs. and 120°C, using an air blast pressure of 40 lbs/in^2 above the chamber pressure. Fig.39 shows the results plotted as pilot fuel flow versus main fuel flow, while Fig.40 shows the overall air fuel ratio plotted against the pilot fuel flow.

6.4 Comparison between different burners of the same design

6.41 In conclusion, as a check on the variation in performance to be expected, under low pressure conditions, among different burners manufactured to the same design, comparative tests were made on three flight type burners, which were numbered 2, 3 and 4, all the tests so far presented in this report having been carried out on No.4.

6.42 The performance of each of these burners under sea level pressure conditions, both as regards combustion stability and air specific impulse, had been determined by previous tests and was known to be substantially identical.

6.43 The comparative tests, the results of which are plotted in Figs.41 to 43, took the form of three sets of stability loops, Fig.41 shows the stability at chamber inlet conditions of 26 ins. Hg.abs. and 120°C, air blast pressure of 40 lbs/in^2 above chamber pressure and with a parallel tailpipe 5 ft.$10\frac{1}{2}$ ins. long.

6.44 Although the stability curves appear similar in shape there is quite a wide scatter in the weak main extinctions.

6.45 Similarly, stability curves were obtained using a 4 ft.3 ins. tailpipe and a 30% restrictor at chamber inlet conditions of 26 ins. Hg.abs. and 120°C. Figs.42 and 43 show the curves obtained by plotting the results when using air blast pressures of 50 and 30 lbs/in^2 above chamber pressure. The shape of the curves differs widely from burner to burner and the experimental scatter is great.

6.46 A dimensional check was made of the burners but examination of this did not give any indication as to the cause of the scatter.

6.47 Limited time did not allow more than a brief attempt to find the cause of the variation in performance. The cone on burner No.4 was moved 0.060 ins. downstream relative to the fuel jets, but this did not alter the performance at 26 ins. Hg.abs. at all (see Fig.41).

6.48 Each burner in turn was mounted on a spray rig with atmospheric inlet air pressure, and in addition to a visual examination of the spray pattern produced by the main jets, a note was made of the fuel flow at which each jet started to spray consistently when the supply was increased from zero. The results are shown in Table I and it will be noted that while burners Nos.2 and 3 have full spray at under 200 lbs/hr, burner No.4 is not functioning completely until 700 lbs/hr.

6.49 For this reason it was decided to make the main fuel spray, on burner No.2, less uniform by blanking one of the main jets. This was done and the result is shown in Fig.41. The shape of the stability curve has altered, the rich main extinctions becoming weaker due to the increased fuel pressure influencing the air blast pressure until choking of the air blast jet occurs; i.e. fuel begins to travel up the air blast jet. It is apparent from this result that the degree of symmetry of the spray issuing from the main jets exercises, as would be expected, a marked

effect on the shape of the stability loop; but, at the same time, it does not appear probable that the whole of the difference between the stability loops produced by the three burners can be attributed to this cause. Unfortunately, lack of time and testing facilities prevented further investigation of this matter.

7 . Discussion and Conclusions

7.1 In the course of the experimental work and from an examination of the results several factors were noted which, although of secondary importance at high chamber inlet pressures, appear, under low pressure conditions, to influence the performance of the burner to a marked degree.

7.2 In the first place it will be seen (from Fig.8 with an air blast pressure of 40 lbs/in^2 for example) that under some operating conditions, with a given pilot fuel flow, the rich extinction curve is re-entrant, i.e. it is possible to obtain two distinct rich extinction limits, and two distinct weak extinction limits for the same pilot fuel flow depending on the manner in which these limits are approached. This phenomenon may, in general, be attributed to an asymmetric, poorly atomised, or pulsating spray issuing from the main fuel jets at low values of main fuel flow, before these jets are functioning properly; however, this explanation is not always valid. This effect, which was not observed on the sea level test rig, becomes important under altitude conditions partly because the flameholding properties of the stabilising cone are already impaired by the decreased inlet air pressure, and partly, owing to the reduced air density, the unstable fuel flow range is moved closer to the stoichiometric mixture strength.

7.3 Secondly, at altitude, the stability of the burner is more sensitive than at sea level to the degree of atomisation and spray pattern produced by the fuel jets. In evidence, the large variation in extinction limits caused by change in air blast pressure, and the inconsistency between different burners of the same design may be quoted. Moreover, the maximum air specific impulse developed, at sea level, always increases very slightly with increase in air blast pressure, whereas at altitude no such simple relationship between the two quantities appears to hold.

7.4 Thirdly, it became increasingly evident as the tests proceeded that some uncontrolled factor was affecting the results, and after a prolonged search it was proved that the physical properties of the fuel, in particular the vapour pressure at the operating temperature affected the combustion limits. This matter, which has only been mentioned briefly in this report, forms the subject of a separate detailed investigation, the results of which are presented in Ref.4.

7.5 Apart from these observations, the effect of reduced inlet pressure on the burner performance follows in general the lines anticipated, and the conclusions drawn from the results may be summarised as follows:-

Conclusions

1. Decrease in chamber inlet pressure below about 1 atmos. abs. is accompanied by a progressive decrease in stability range.

2. The maximum air specific impulse also decreases with inlet pressure, and the mixture strength at which this maximum impulse is developed becomes richer, probably because a considerable fraction of the total fuel injected remains unburnt.

3. By selecting the appropriate operating conditions (pilot fuel flow, and air blast pressure) stable combustion can be maintained at a chamber inlet pressure of 16 ins. Hg.abs. At these conditions the burner develops a maximum air specific impulse of 133 at an air fuel ratio of 8:1, using a tailpipe 5 ft.10½ ins. in length.

4. An increase in chamber inlet temperature weakens both the weak and rich extinction limits and increases the maximum air specific impulse. This behaviour, which also occurs at sea level condition, is presumably a direct result of the increased vaporisation of the fuel at the higher temperature.

5. A change in tailpipe length from 5 ft to 5 ft.10½ ins. does not affect the stability limits appreciably, except at points where the extraneous effects referred to in para.7.2 exert an overriding influence on the performance.

6. As expected, the maximum air specific impulse developed increases with increase in tailpipe length, probably because with the longer pipe the time available for combustion is greater.

7. The effect of tailpipe exit restriction on stability is somewhat irregular, but, in general, an increase in restriction closes the stability loop, and appears to exaggerate the effect referred to in para.7.2.

8. As regards the effect of tailpipe restriction on maximum air specific impulse, it appears that, as the percentage restriction is increased from zero, the maximum air specific impulse also increases until it reaches a value of approximately 150 with 15% restriction. When, however, this optimum condition is reached, the stability range has become so small, that further restriction is only possible in conjunction with a decrease in tailpipe length and no further increase in air specific impulse can be obtained by these means.

This situation is analogous to several previously encountered during ground level tests with different designs of ramjet burners,[2] it being found impossible to increase the maximum air specific impulse above a critical value by any means whatever without the intervention of violent and unstable combustion.

LIST OF REFERENCES

No.	Author	Title, etc.
1	A.G. Earl, R.D. Swift and S.W. White	The Sea Level Performance Characteristics of a 6" diameter Anvil Jet Ramjet Kerosine Burner. RAE T.N. GW.146. November 1951.
2	J. Reid	The Further Development of a 6" diameter Ramjet Combustion Chamber. RAE Report GW.12. March, 1952.
3	P. Philpot	An Apparatus for Thrust Measurement on Ramjet Rigs. RAE T.N. GW.69. April 1950.
4	J.S. Drabble	The Effect of Variations in the Vapour Pressure of Standard Aviation Kerosine on the Performance of a "Reid" Air Blast Ramjet Combustion Chamber. (In course of preparation.)

Attached: Table I
Drg.Nos. GW/P/4089 to 4121
Detachable Abstract Cards

Advance Distribution:

M.O.S. Headquarters

Chief Scientist
CGWL
CS(A)
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R.A.E.

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TABLE I

	Fuel Flow (lbs/hr.)		
Burner No.	2	3	4
Jet No.			
1	55	50	150
2	55 - 180	50 - 150	700
3	55 - 180	50 - 150	150

The jets are numbered in a clockwise direction, starting from the pilot jet, looking downstream.

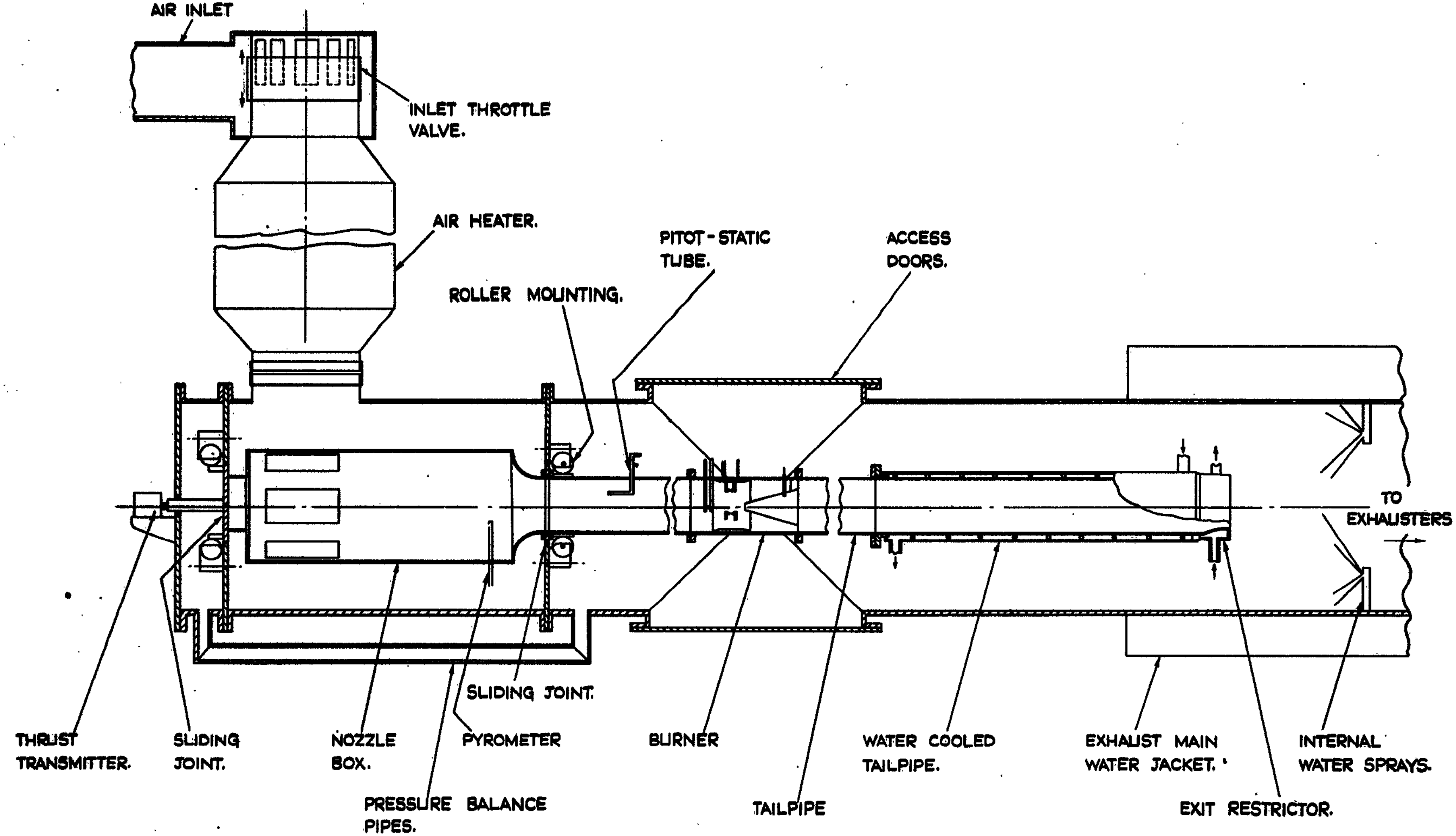


FIG. I LOW PRESSURE RAMJET COMBUSTION RIG. R.A.E.

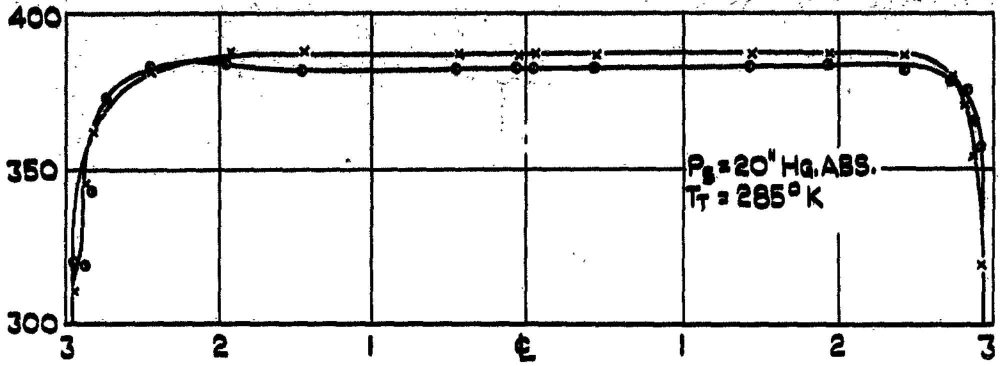


FIG. 2

× VERTICAL TRAVERSE
⊙ HORIZONTAL TRAVERSE

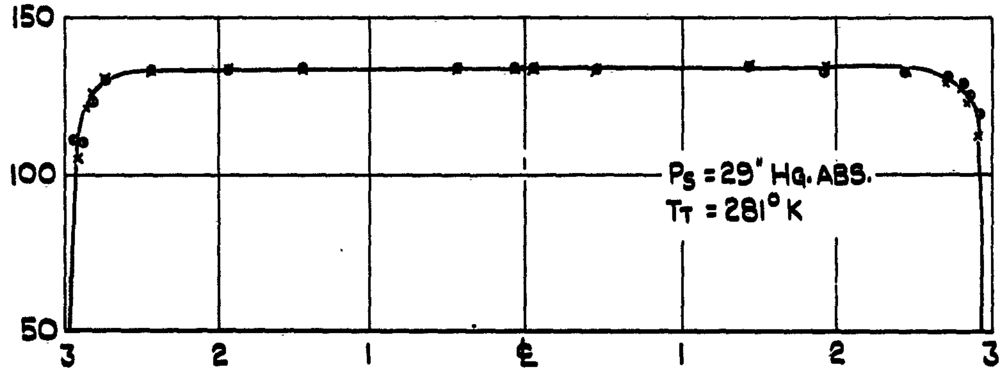


FIG. 3

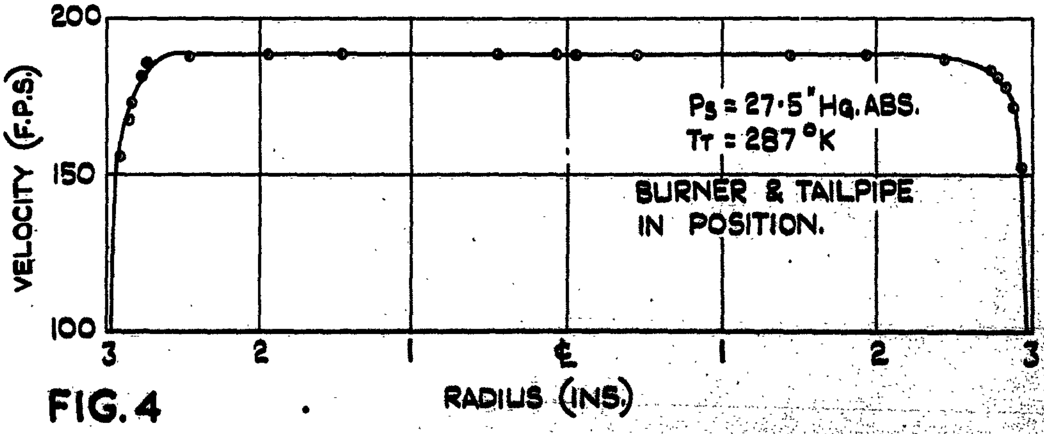


FIG. 4

FIG. 2, 3 & 4 VELOCITY DISTRIBUTION AT CHAMBER INLET.

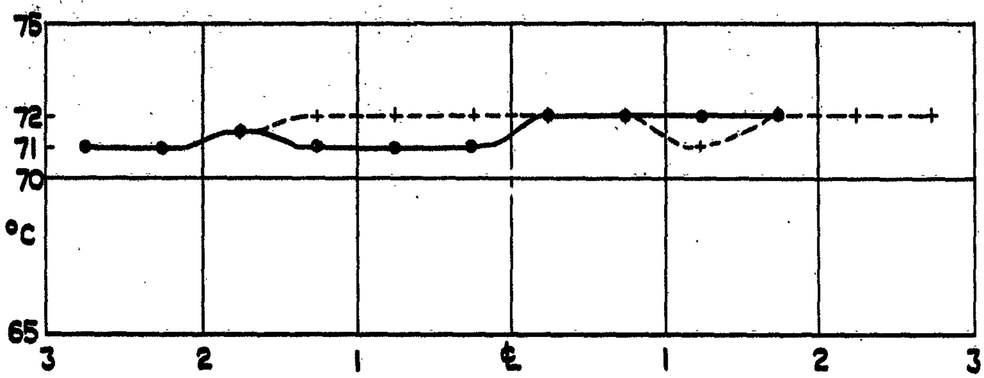


FIG. 5. 'TATE' HEATER.

+ VERTICAL TRAVERSE
⊙ HORIZONTAL TRAVERSE

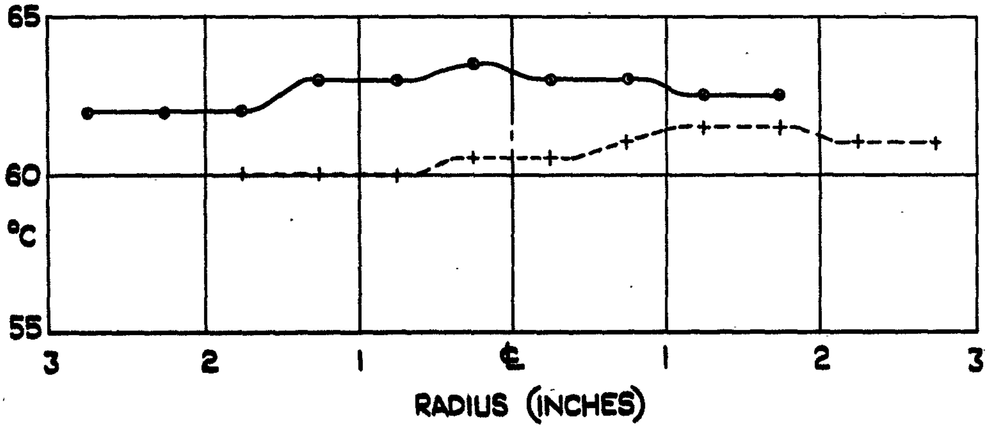


FIG. 6. 'R.A.E.' HEATER.

FIG. 5 & 6 TEMPERATE DISTRIBUTION AT CHAMBER INLET.

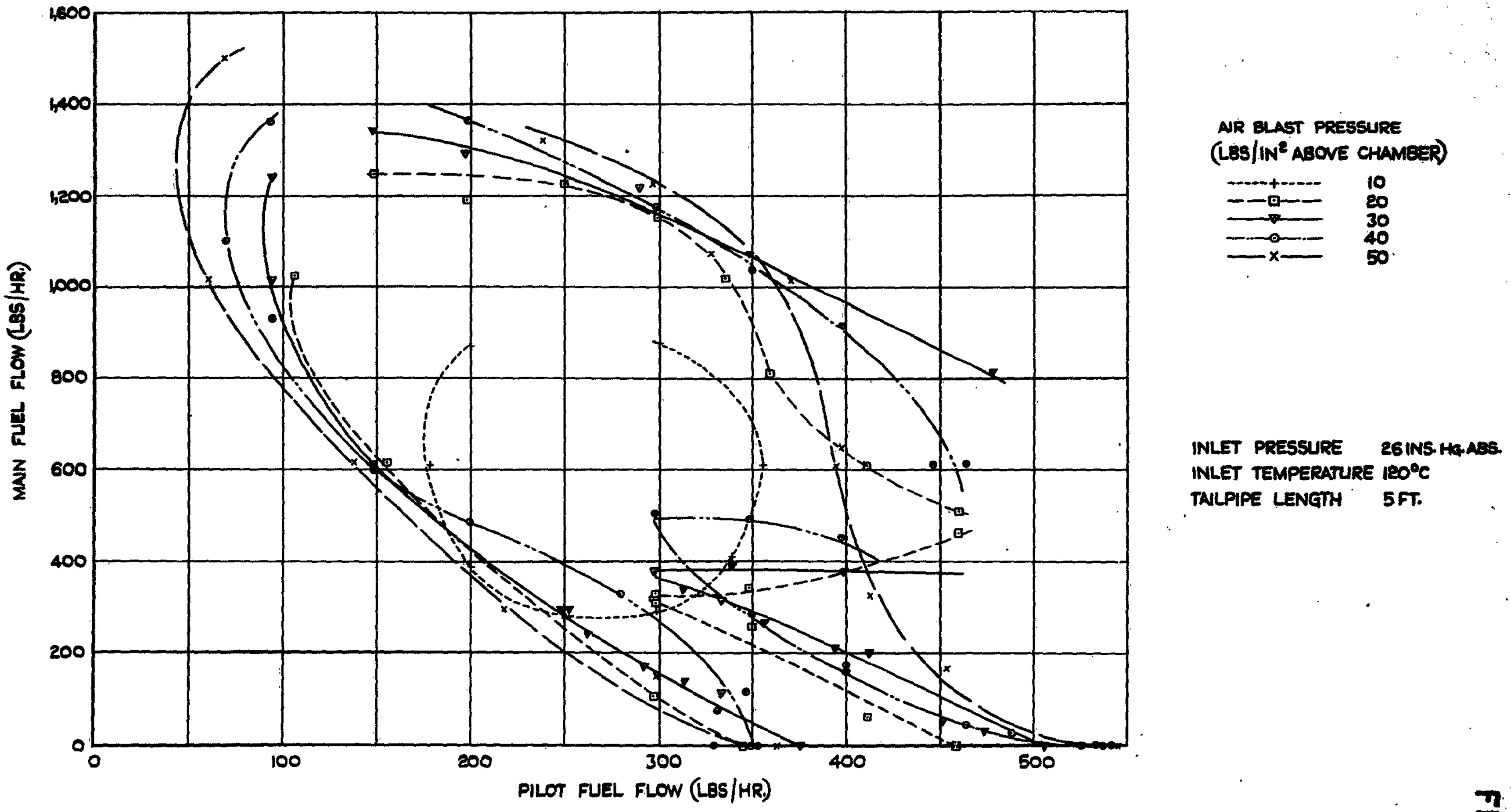


FIG. 7 STABILITY CURVES.

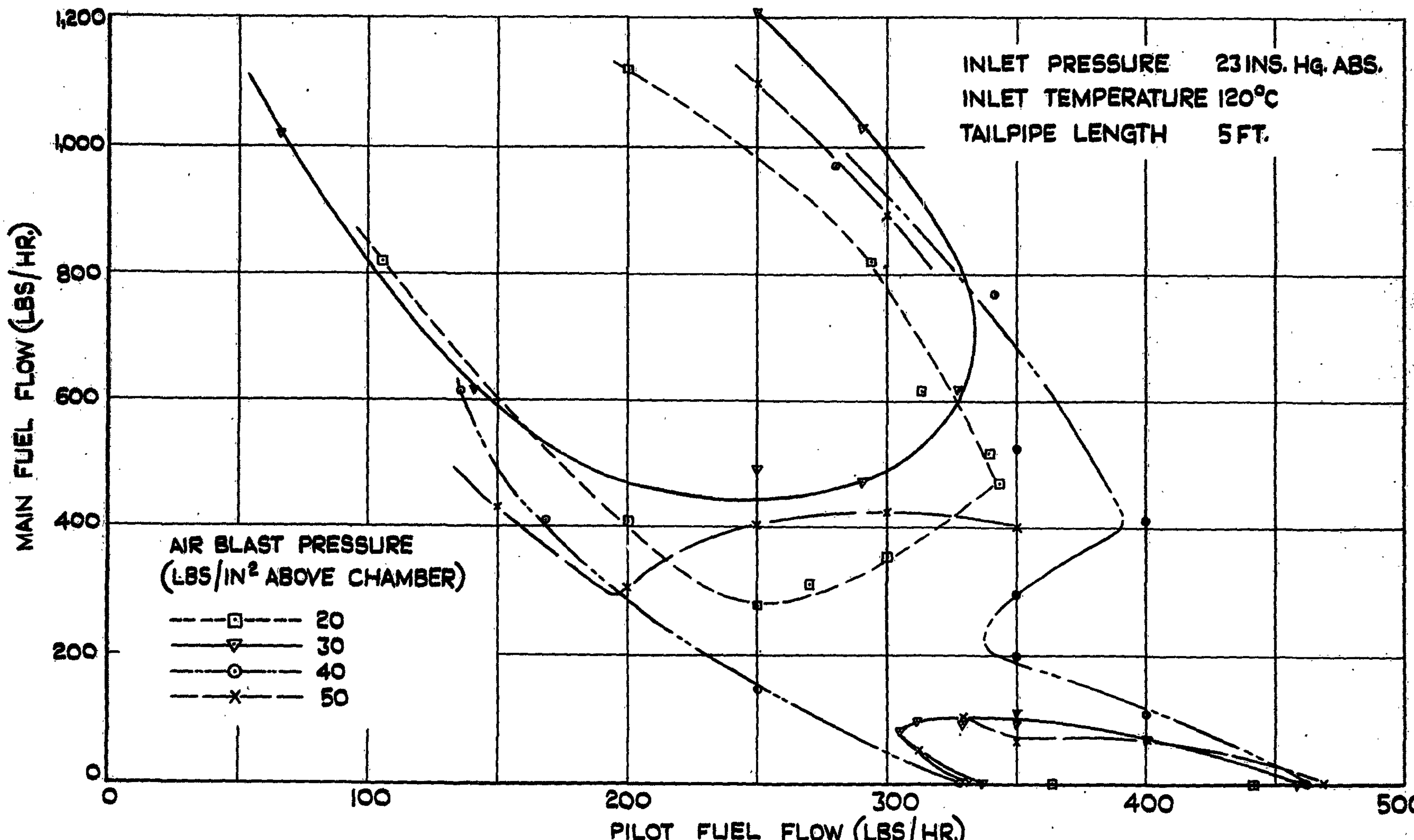


FIG. 8 STABILITY CURVES.

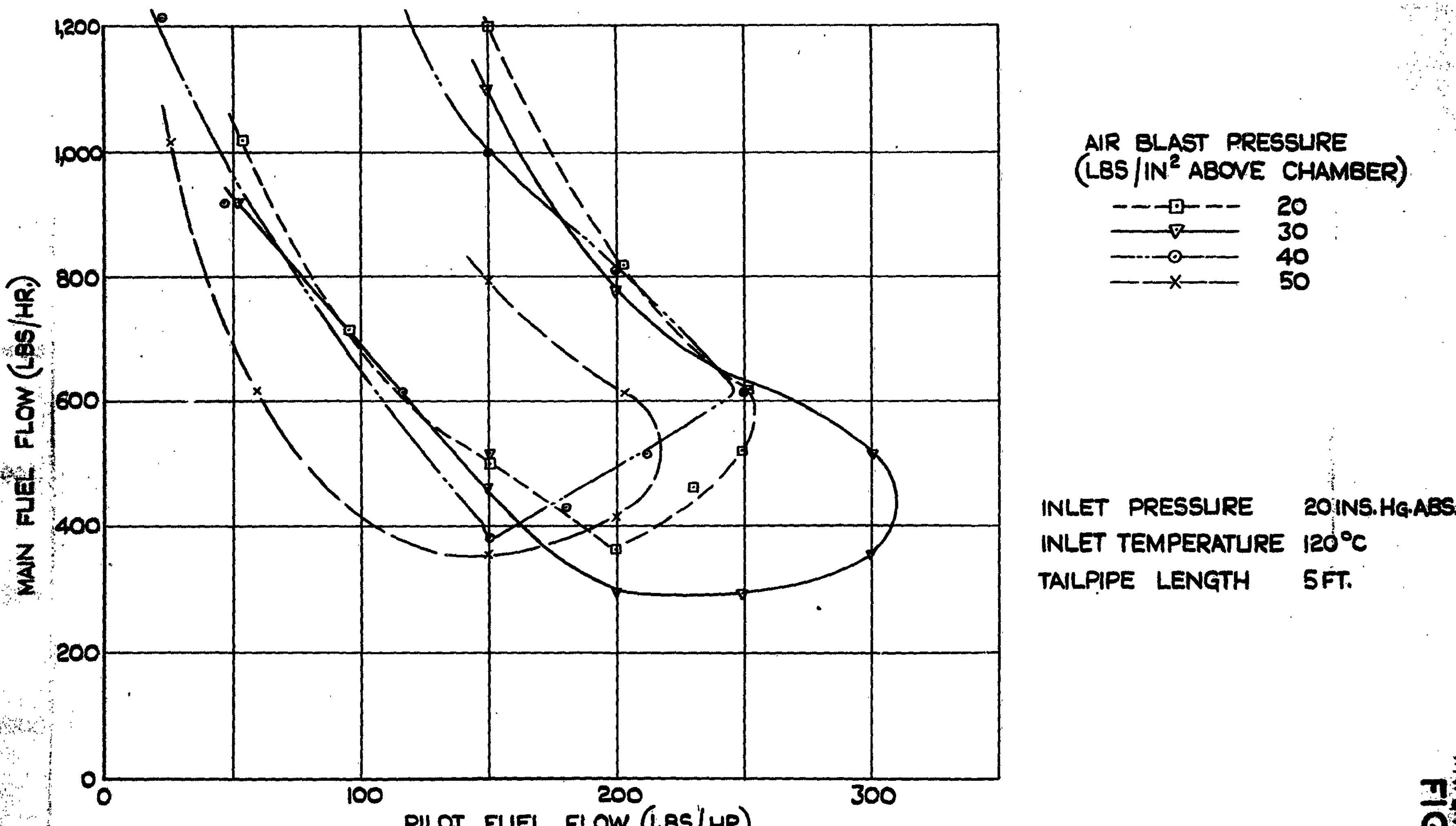


FIG. 9 STABILITY CURVES.

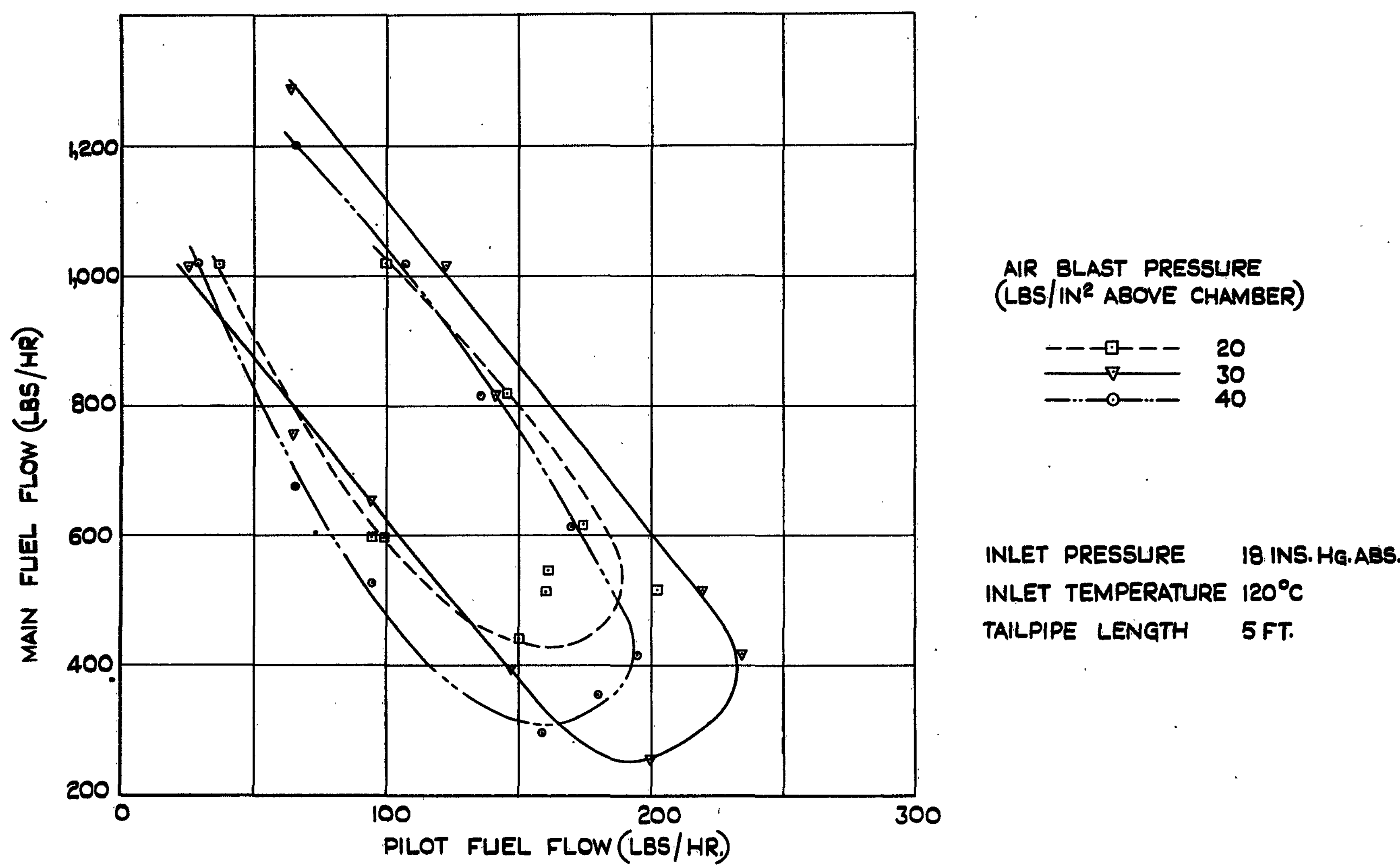


FIG. 10 STABILITY CURVES.

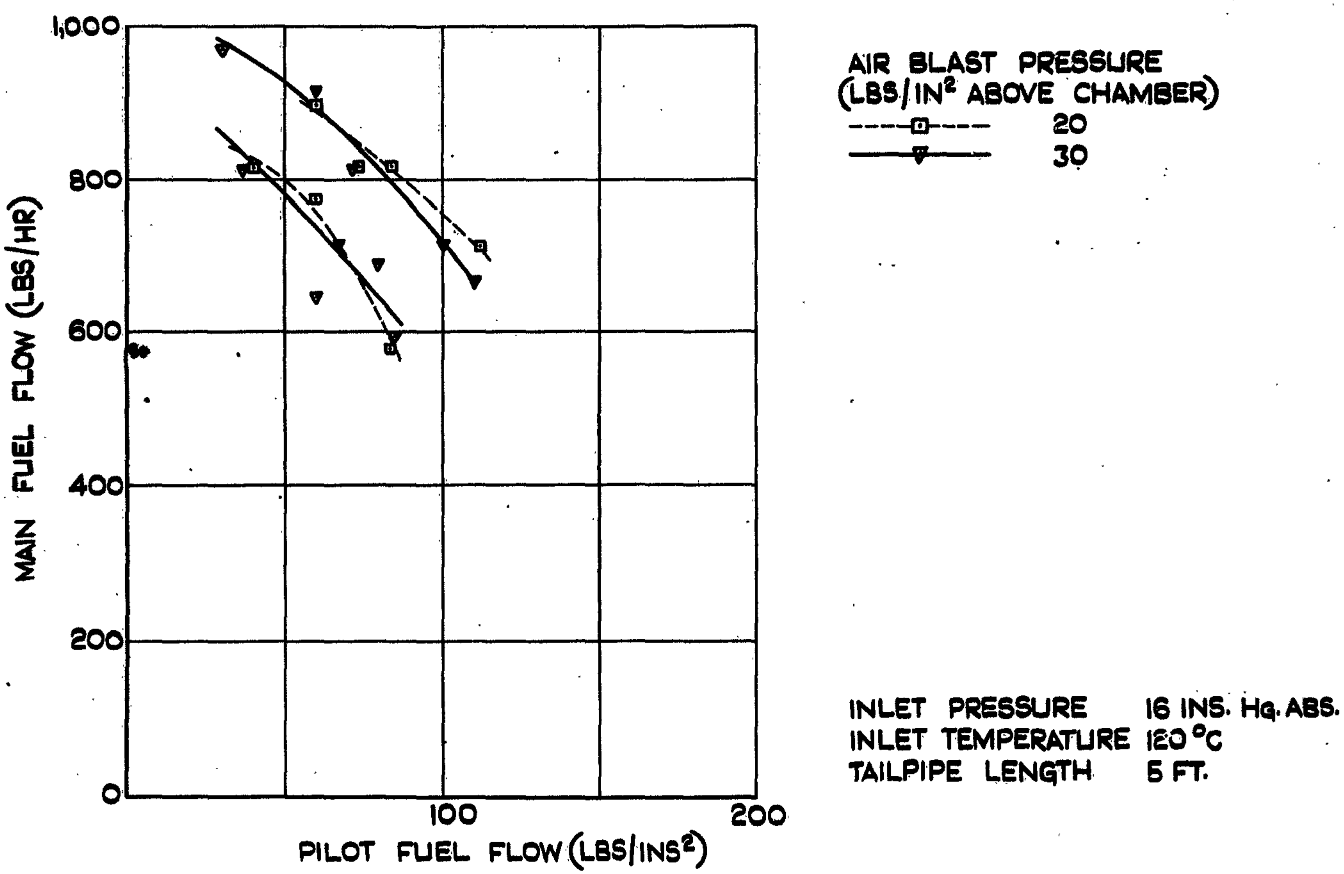


FIG.11. STABILITY CURVES.

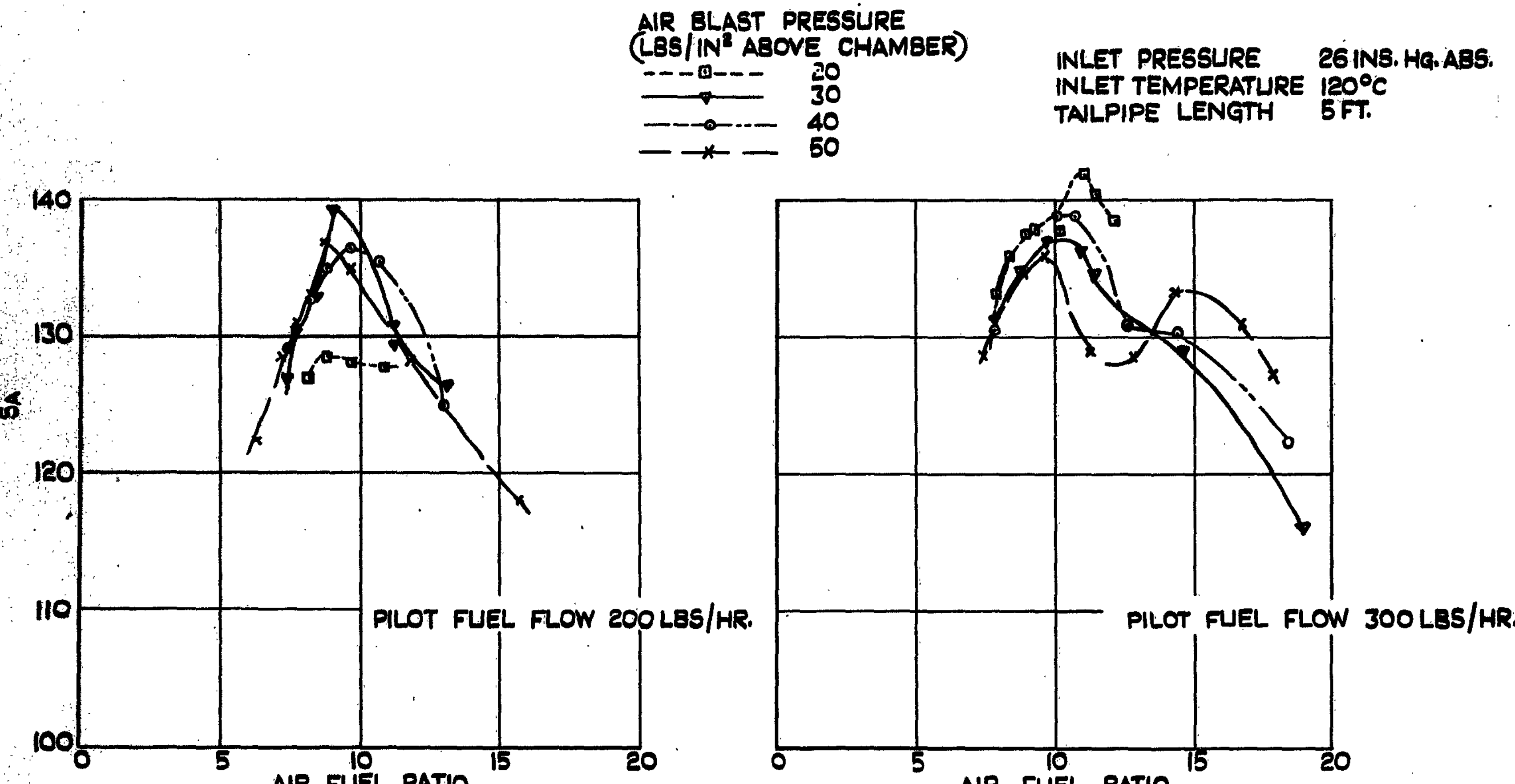


FIG 12.

FIG 13.

FIG 12 & 13. AIR SPECIFIC IMPULSE
VERSUS AIR FUEL RATIO.

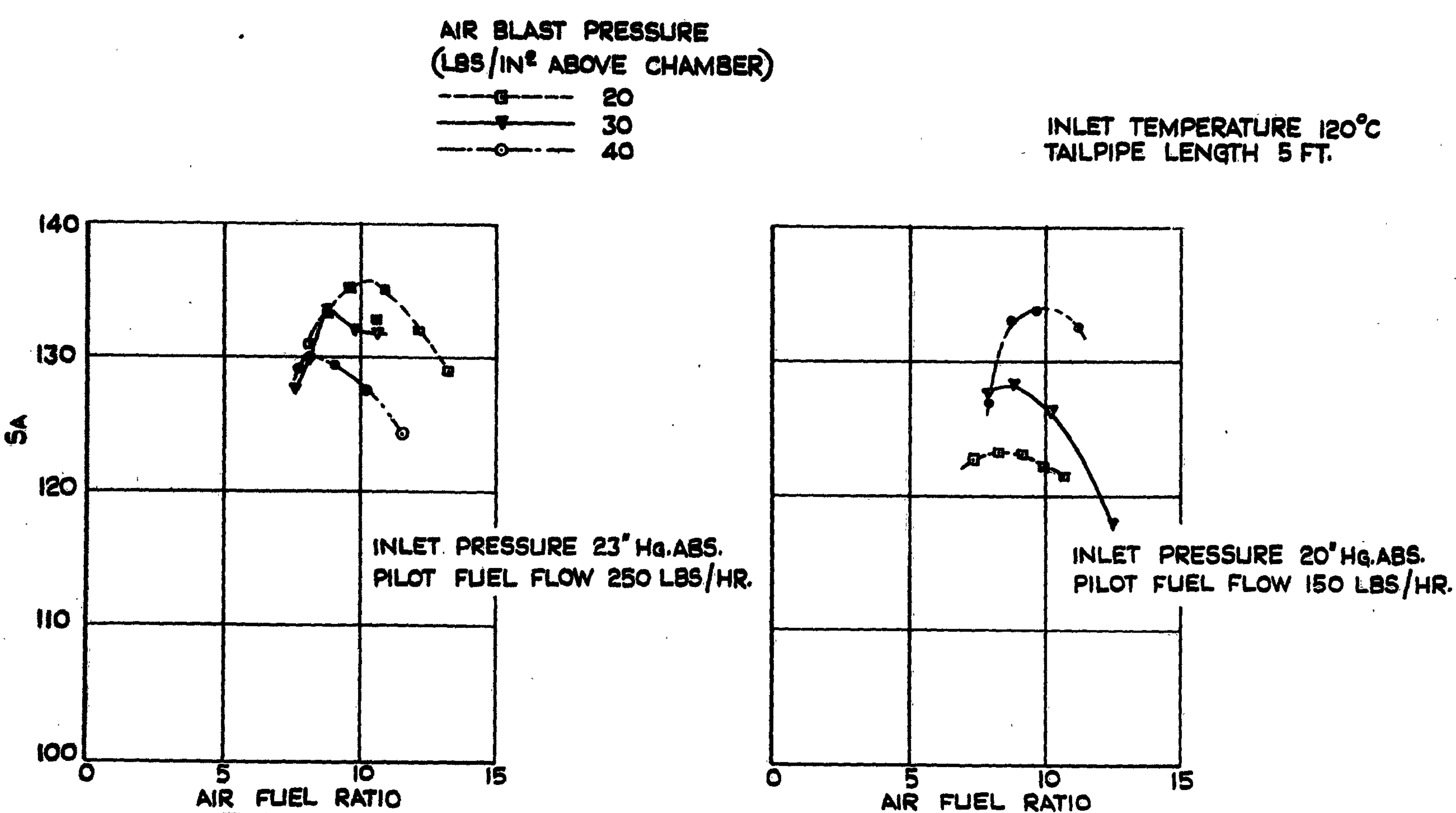


FIG 14.

FIG.15

FIG 14 & 15. AIR SPECIFIC IMPULSE VERSUS AIR FUEL RATIO.

INLET PRESSURE 18 INS. Hg. ABS.
INLET TEMPERATURE 120°C
TAILPIPE LENGTH 5 FT.
PILOT FUEL FLOW 100 LBS/HR.

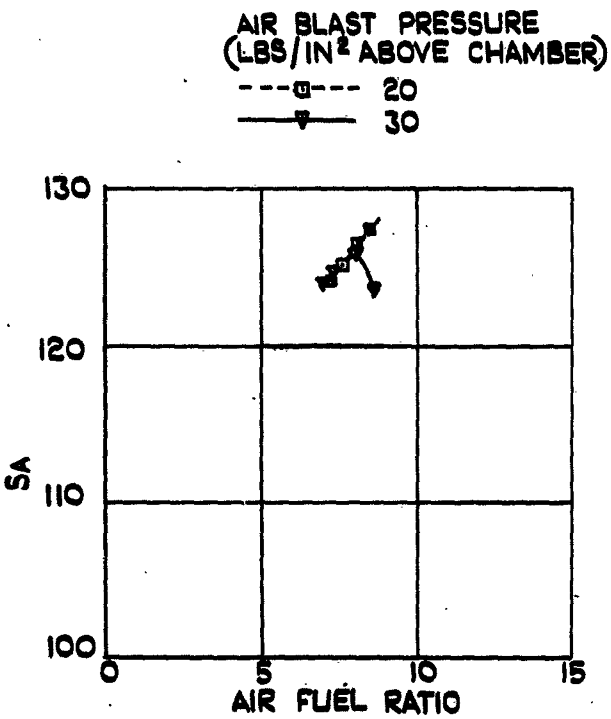


FIG. 16. AIR SPECIFIC IMPULSE VERSUS AIR FUEL RATIO.

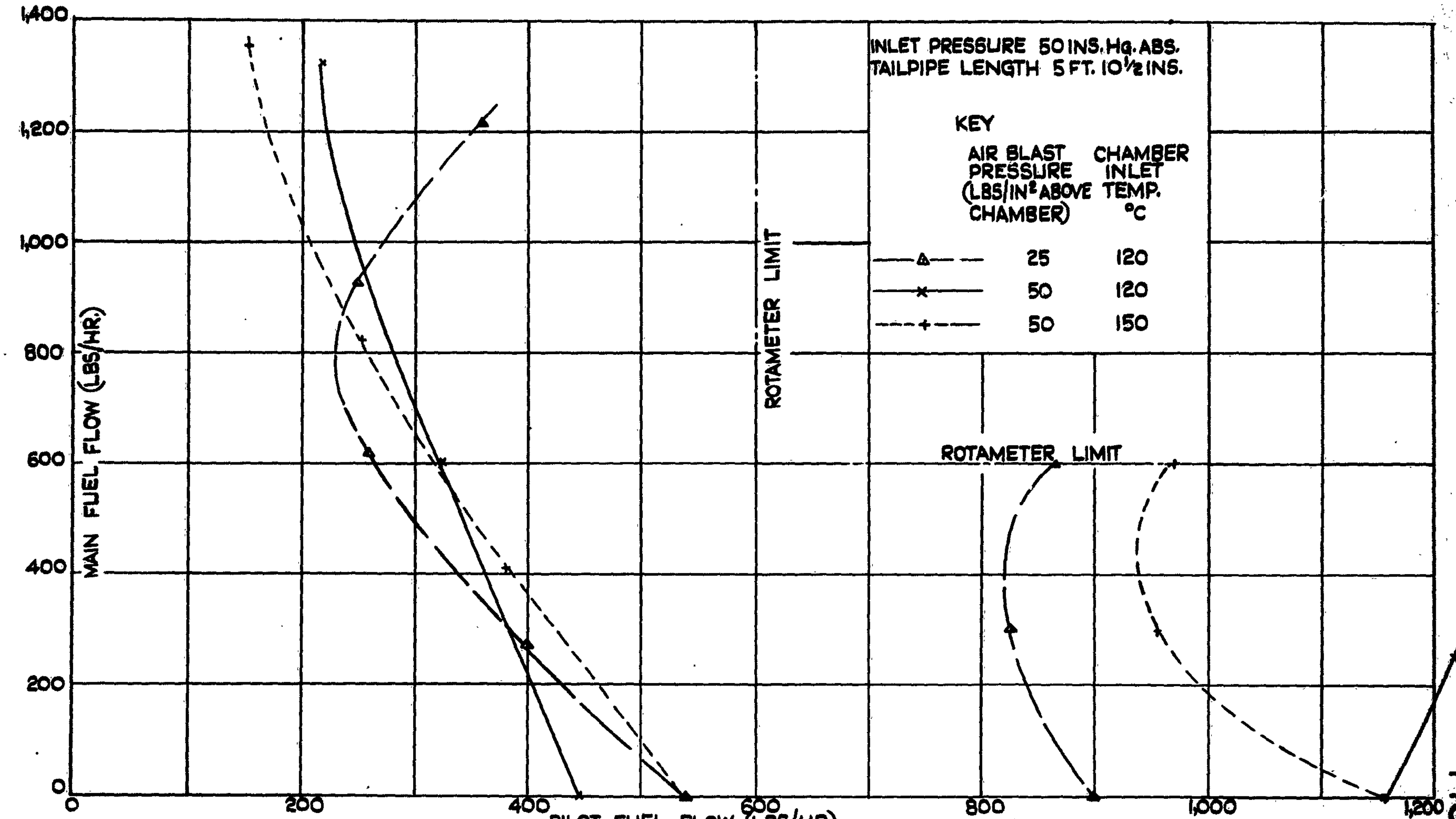


FIG 17. STABILITY CURVES.

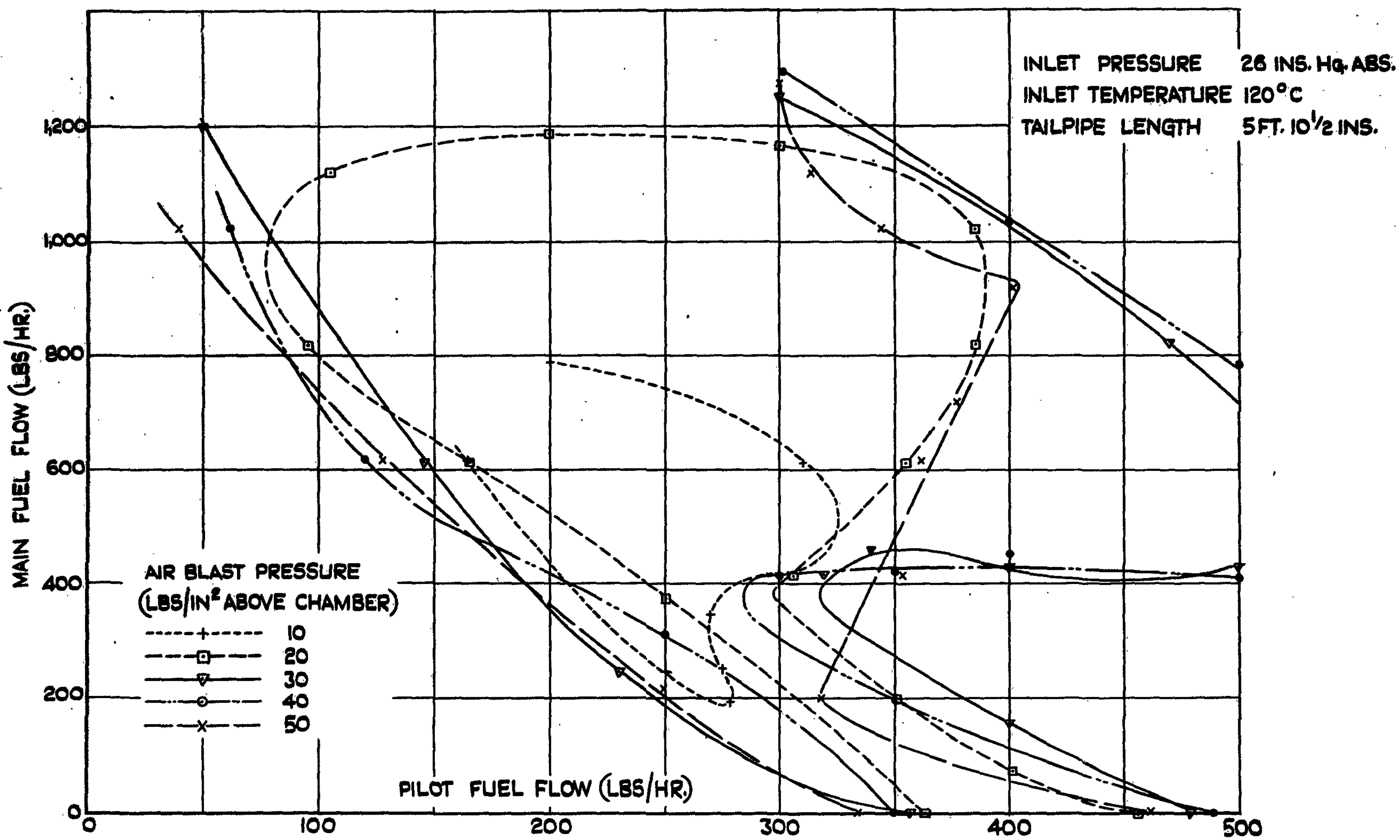


FIG. 18 STABILITY CURVES.

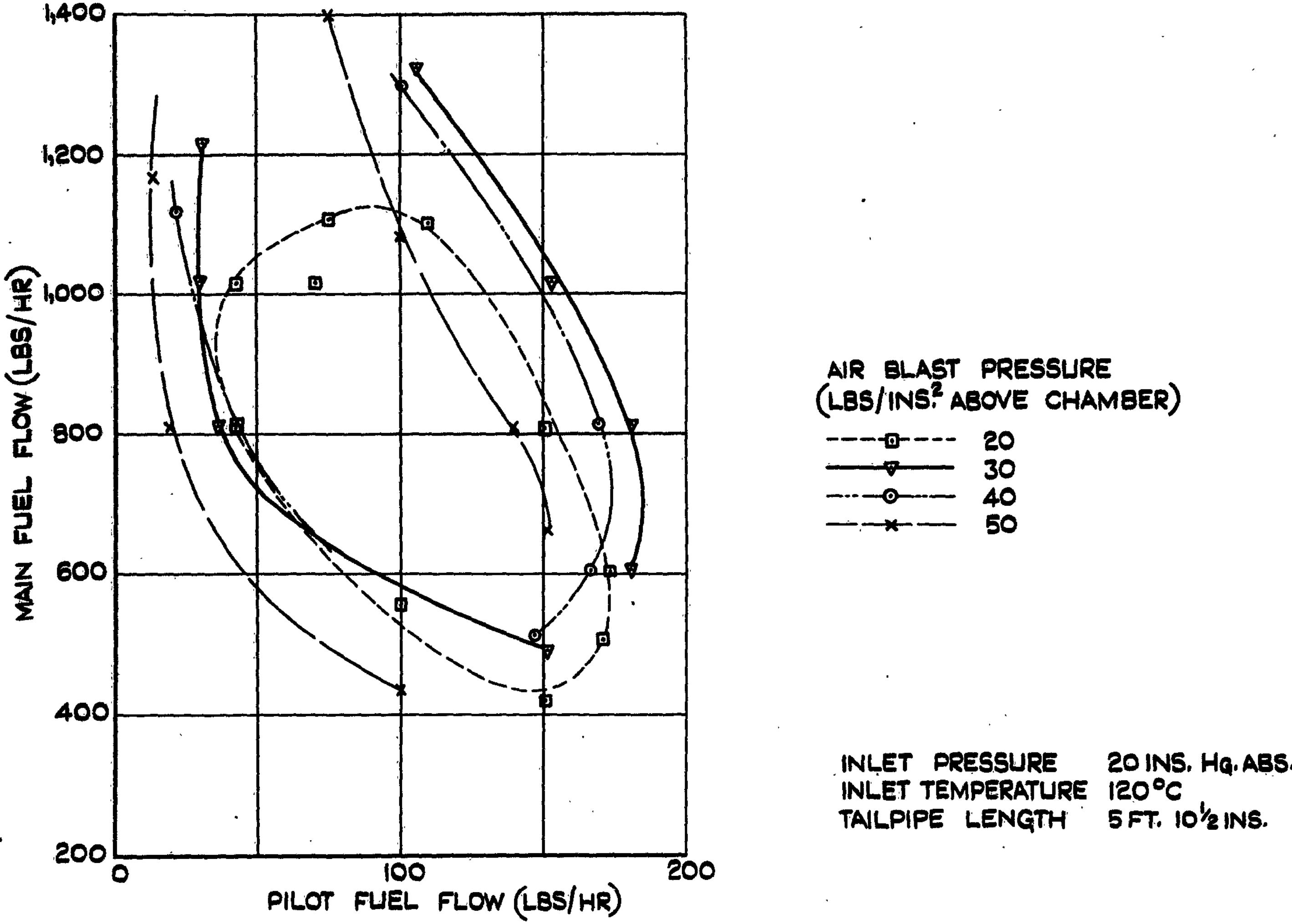
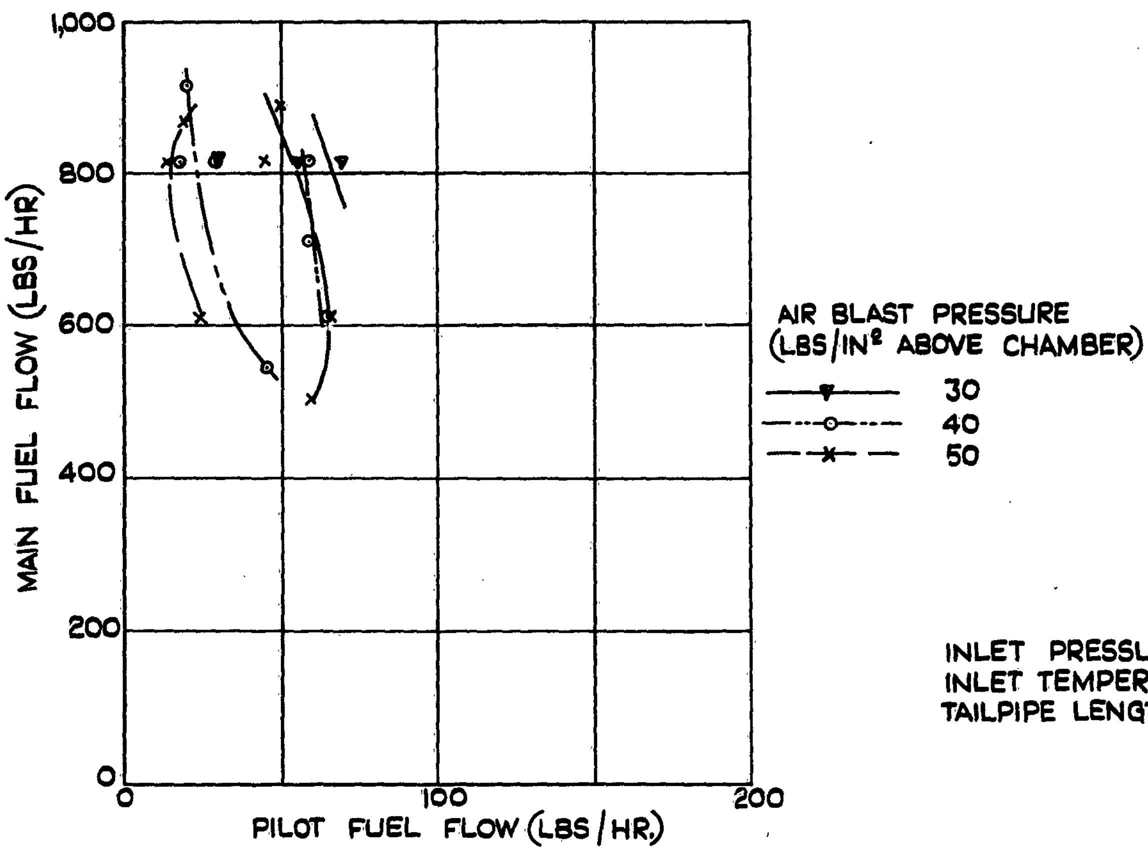


FIG. 19. STABILITY CURVES.



INLET PRESSURE 16 INS. HG. ABS.
INLET TEMPERATURE 120°C
TAILPIPE LENGTH 5 FT. 10½ INS.

FIG 20. STABILITY CURVES.

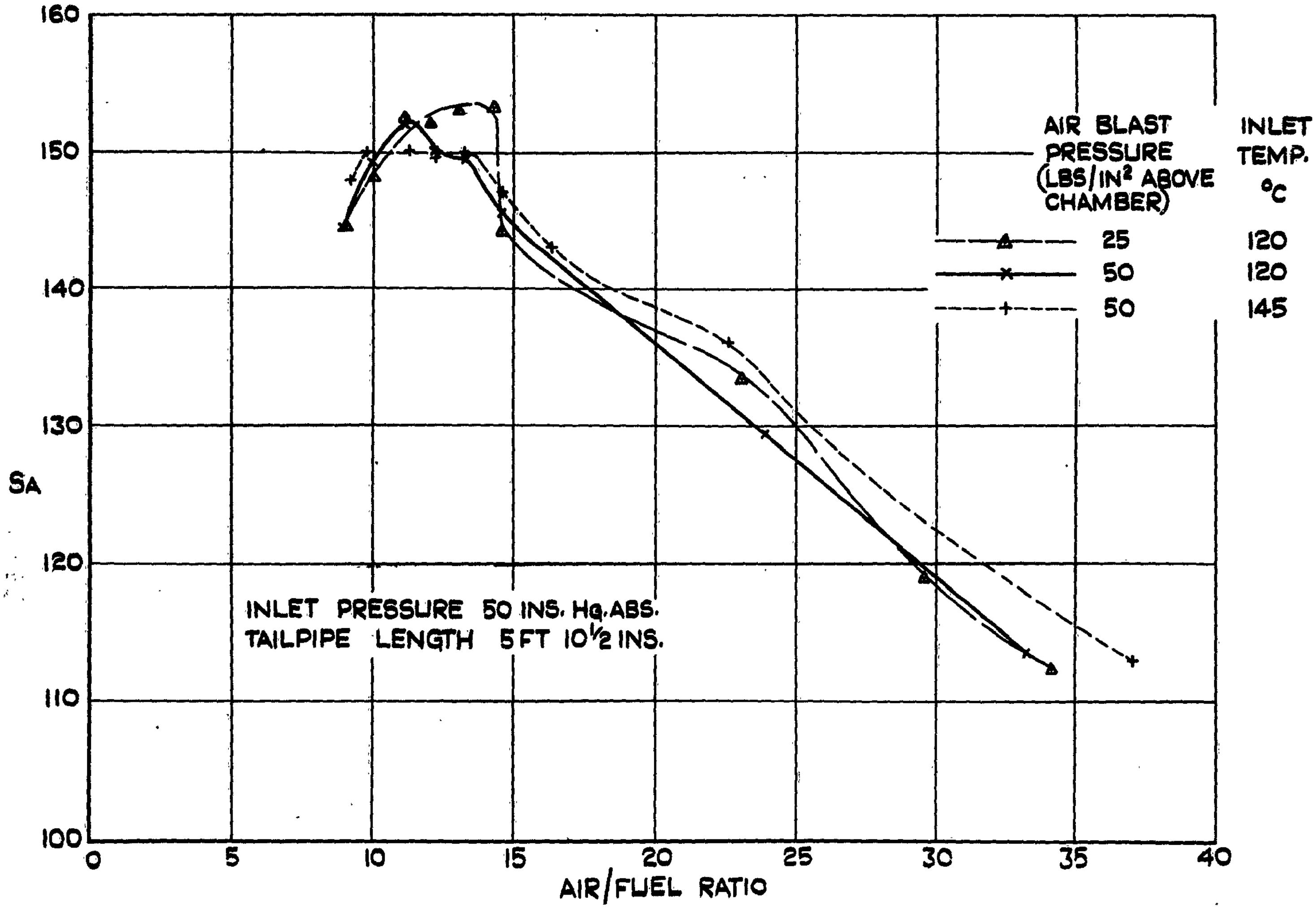


FIG. 21. AIR SPECIFIC IMPULSE VERSUS AIR FUEL RATIO.

AIR BLAST PRESSURE
(LBS/IN² ABOVE CHAMBER)

- ---□--- 20
- ——▽—— 30
- —·—⊙—·— 40
- ——×—— 50

INLET TEMPERATURE 120°C
TAILPIPE LENGTH 5FT. 10½INS.

INLET PRESSURE 26 INS. HG. ABS.
PILOT FUEL FLOW 300 LBS/HR.

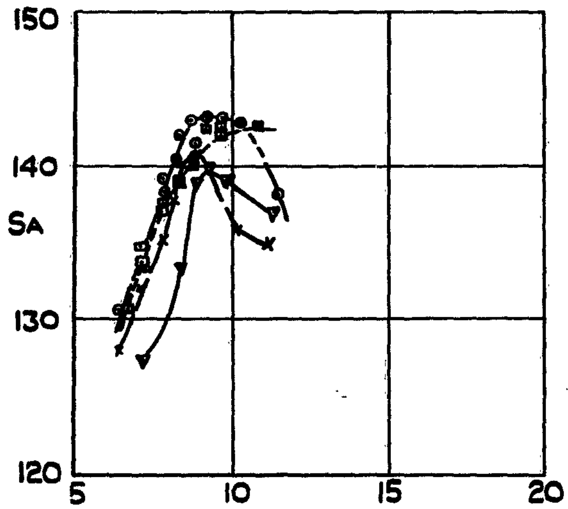


FIG 22

20 INS. HG. ABS.
100 LBS/HR.

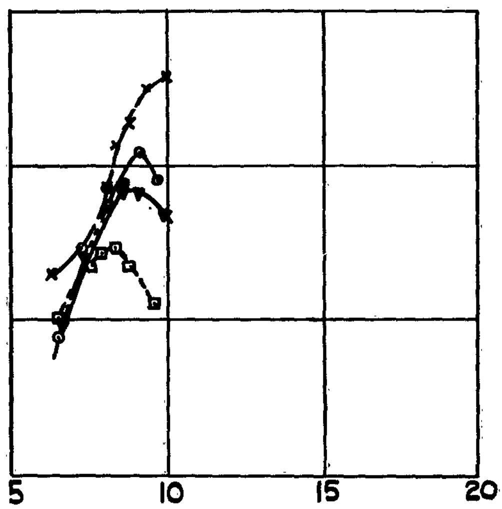


FIG.23

16 INS. HG. ABS.
46 LBS/HR.

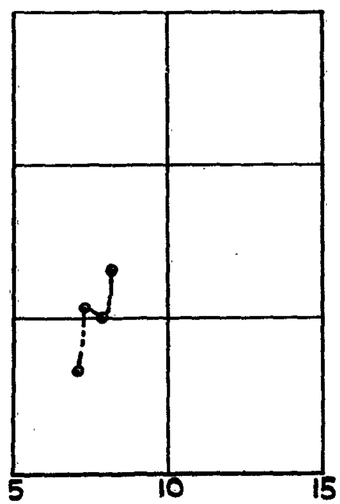


FIG 24.

FIG 22, 23, & 24. AIR SPECIFIC IMPULSE VERSUS AIR FUEL RATIO.

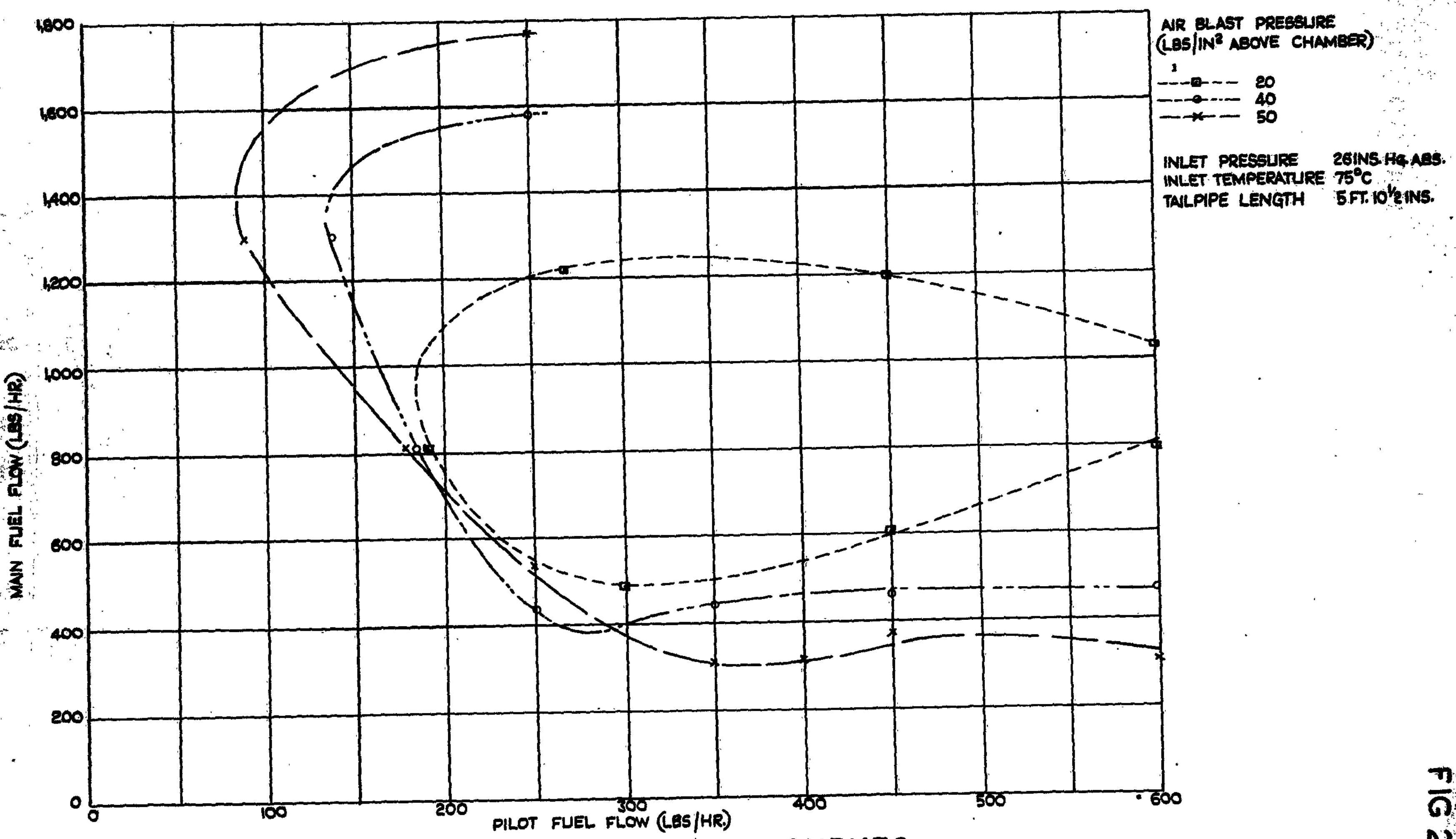


FIG 25. STABILITY CURVES.

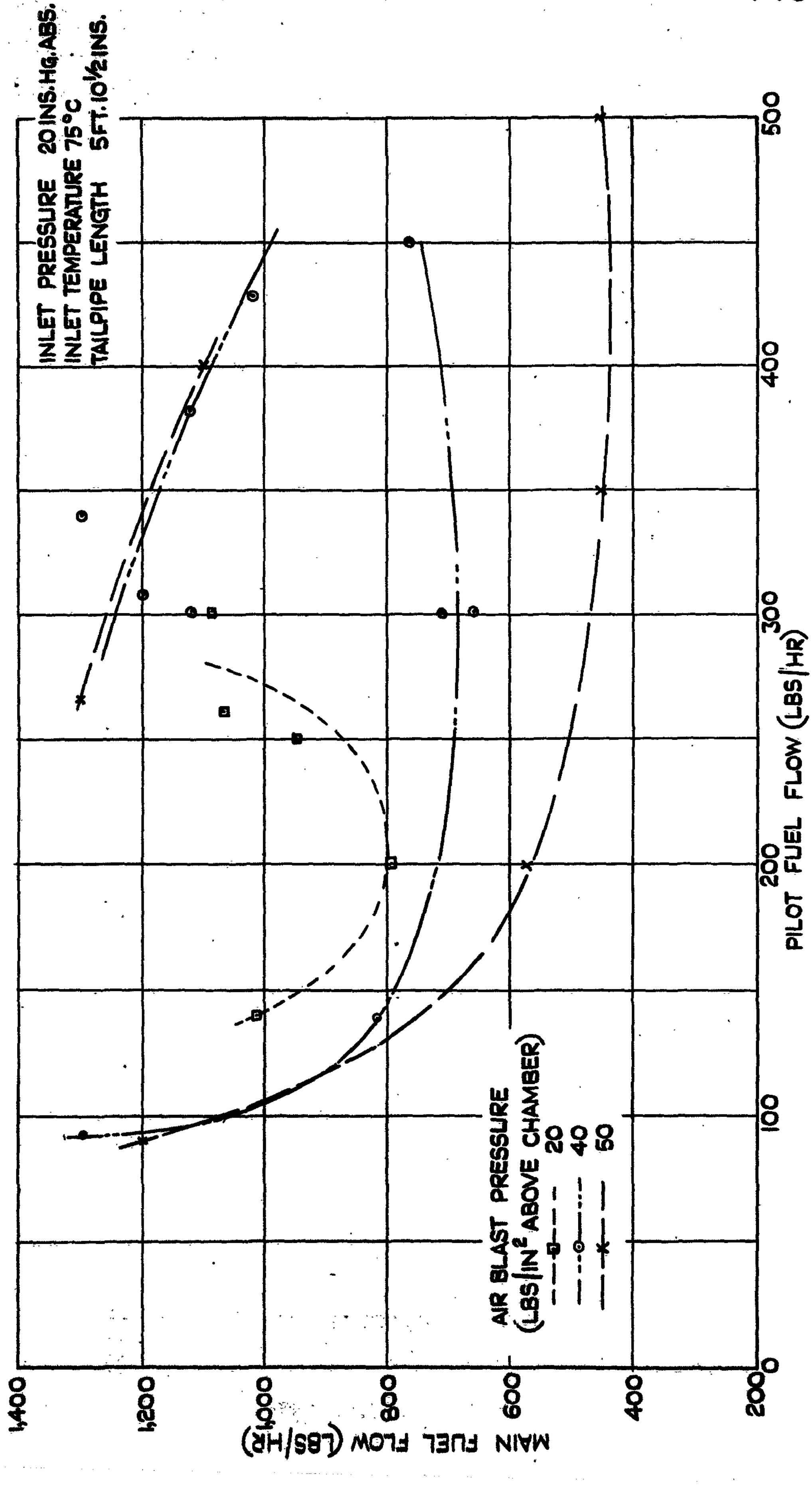


FIG 26. STABILITY CURVES.

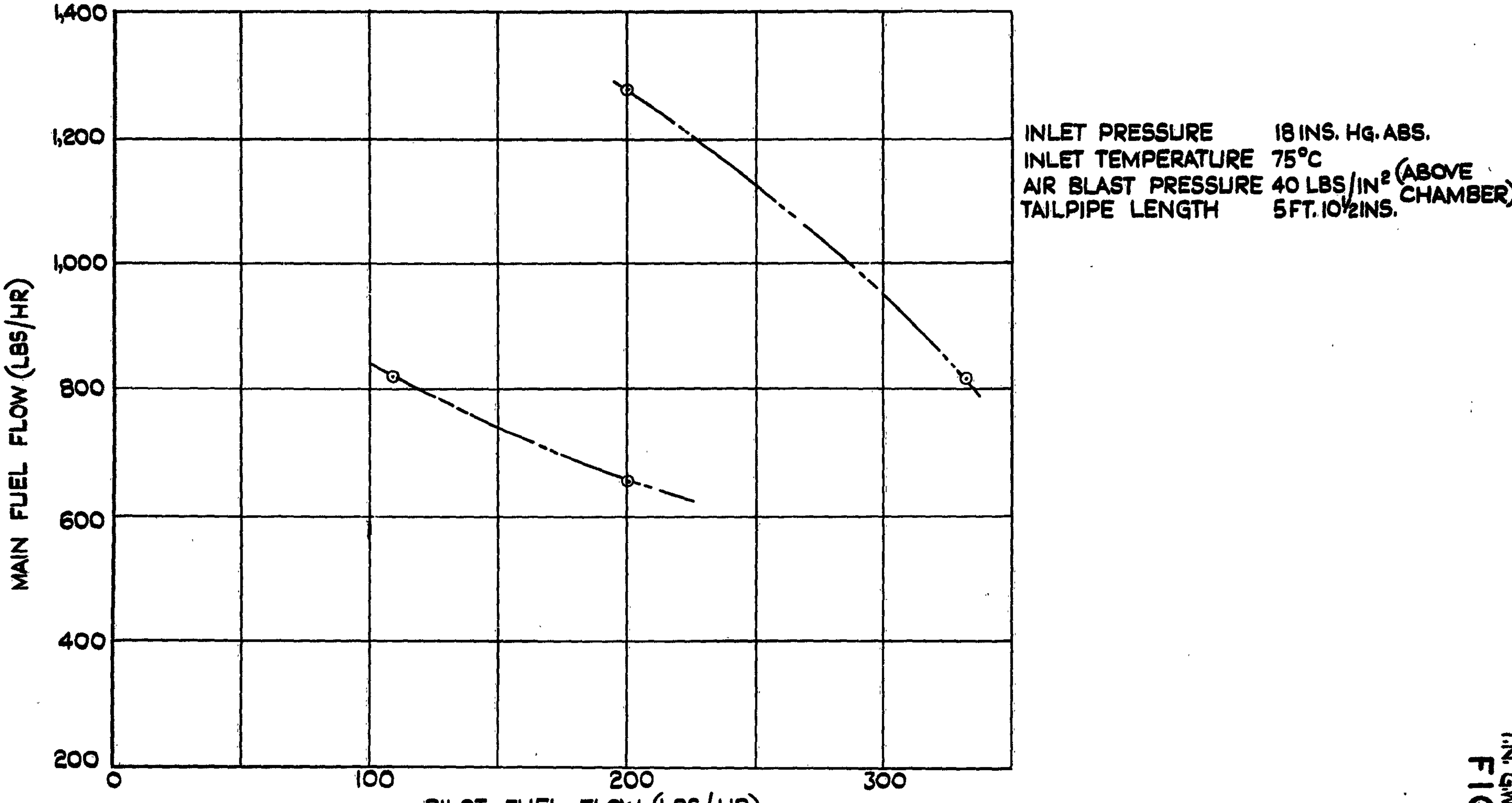


FIG 27. STABILITY CURVE.

AIR BLAST PRESSURE
(LBS/IN² ABOVE CHAMBER)
—o— 40
—x— 50

INLET TEMPERATURE 75°C
TAILPIPE LENGTH 5FT. 10½ INS.

INLET PRESSURE 26 INS. HG. ABS.
PILOT FUEL FLOW 300 LBS/HR.

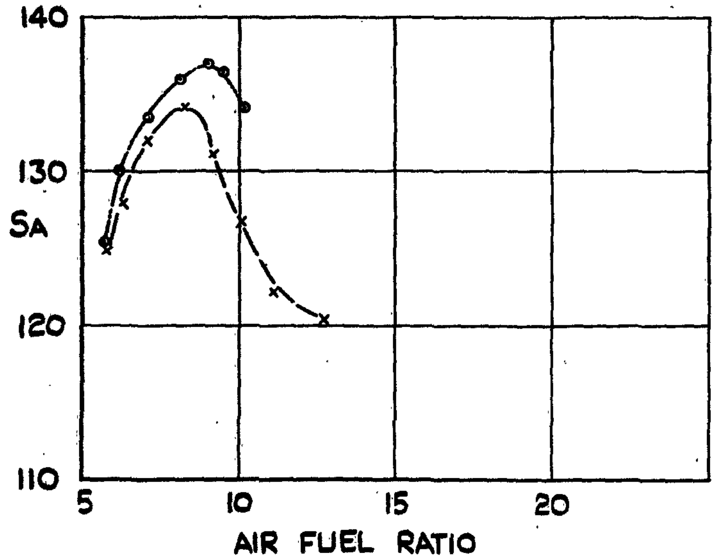


FIG. 28

INLET PRESSURE 20 INS. HG. ABS.
PILOT FUEL FLOW 150 LBS/HR.

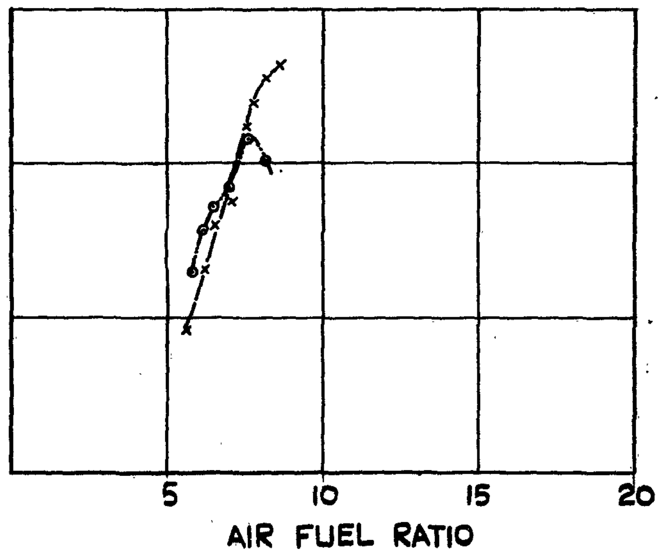


FIG. 29

FIG. 28 & 29 AIR SPECIFIC IMPULSE VERSUS AIR FUEL RATIO.

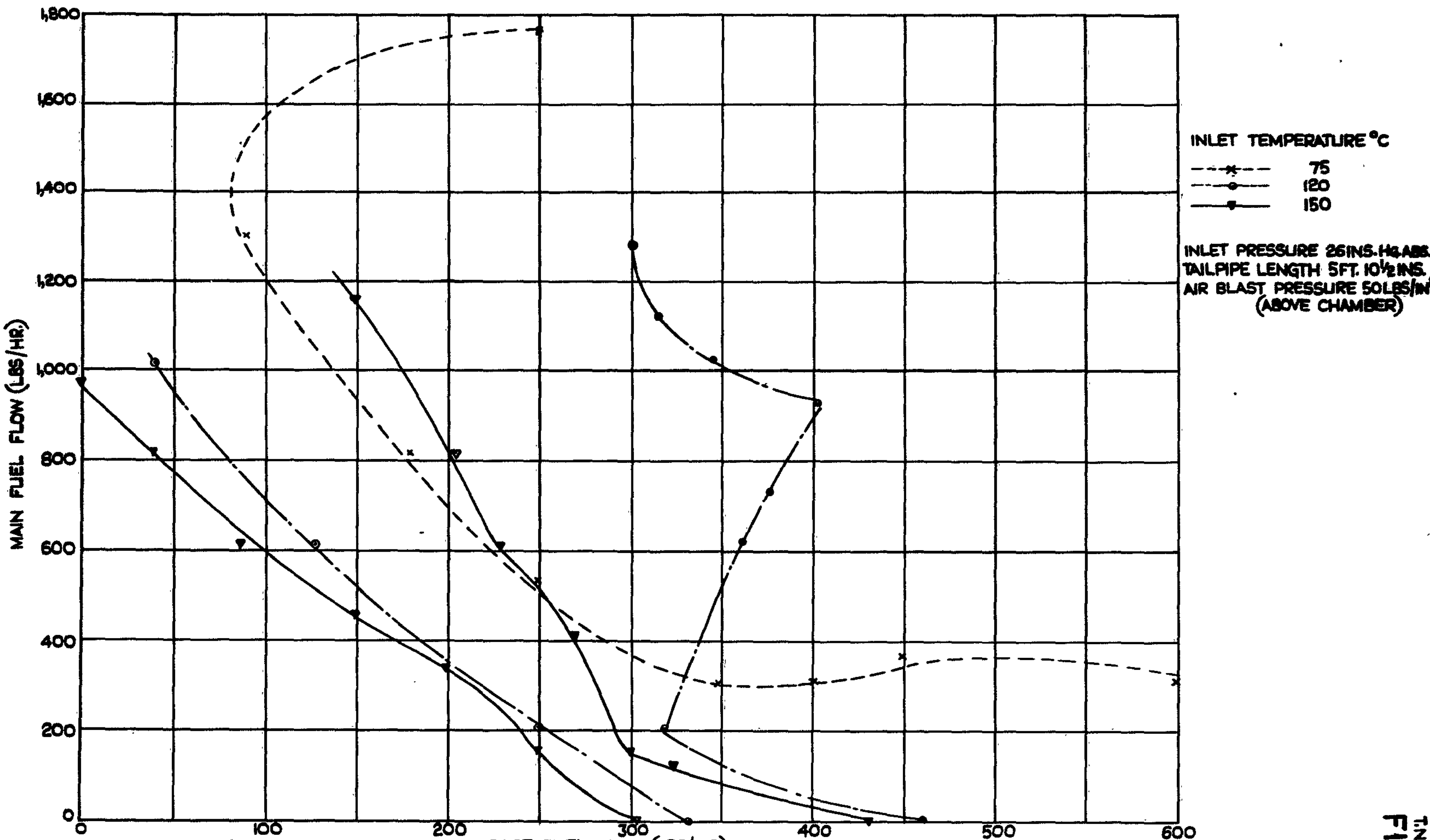


FIG 30. STABILITY CURVES SHOWING EFFECT OF INLET TEMPERATURE.

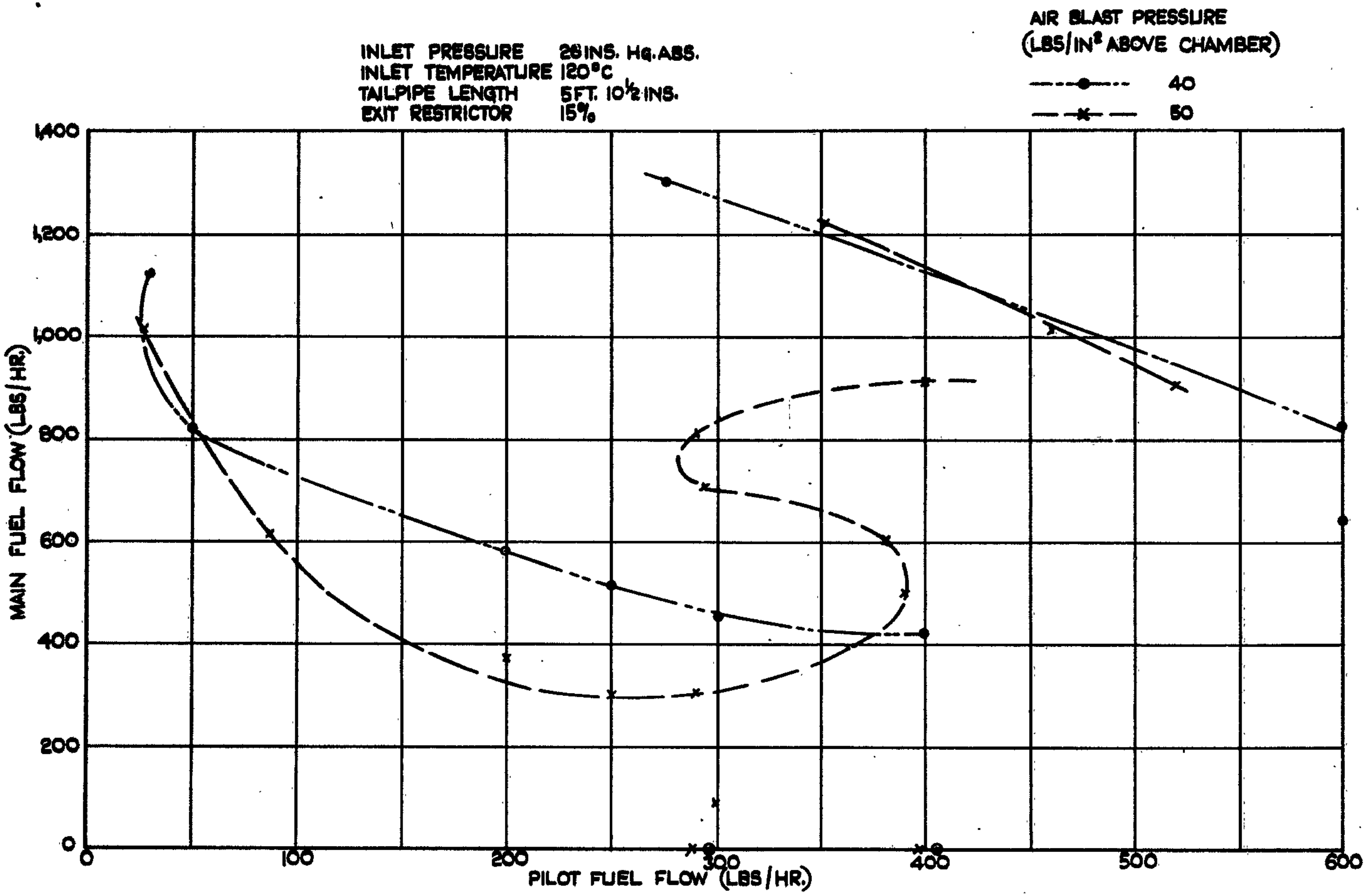


FIG 31. STABILITY CURVES.

AIR BLAST PRESSURE
(LBS/IN² ABOVE CHAMBER)
—·—⊙—·— 40
— —×— — 50

INLET TEMPERATURE 120°C
TAILPIPE LENGTH 5 FT. 10½ INS.
EXIT RESTRICTOR 15%

INLET PRESSURE 26 INS. HG. ABS.
PILOT FUEL FLOW 300 LBS/HR.

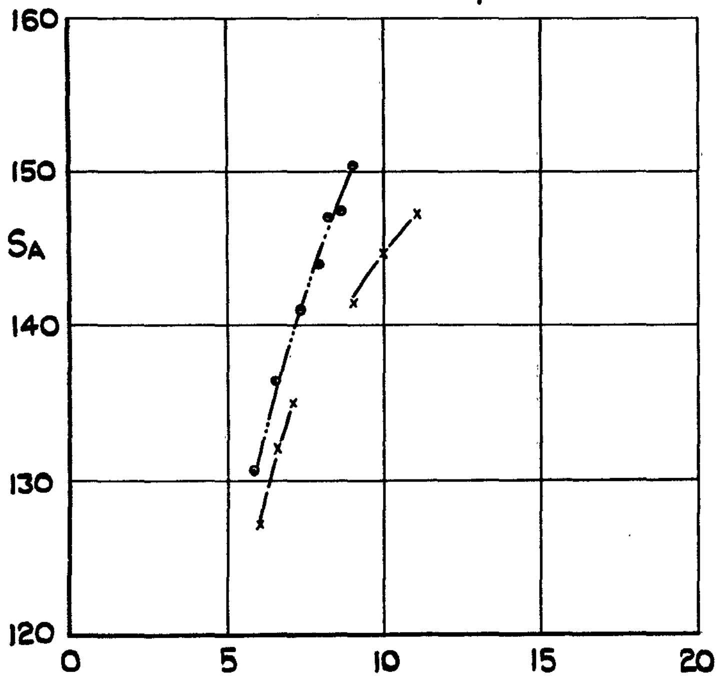


FIG. 32

INLET PRESSURE 20 INS. HG. ABS.
PILOT FUEL FLOW 100 LBS/HR.

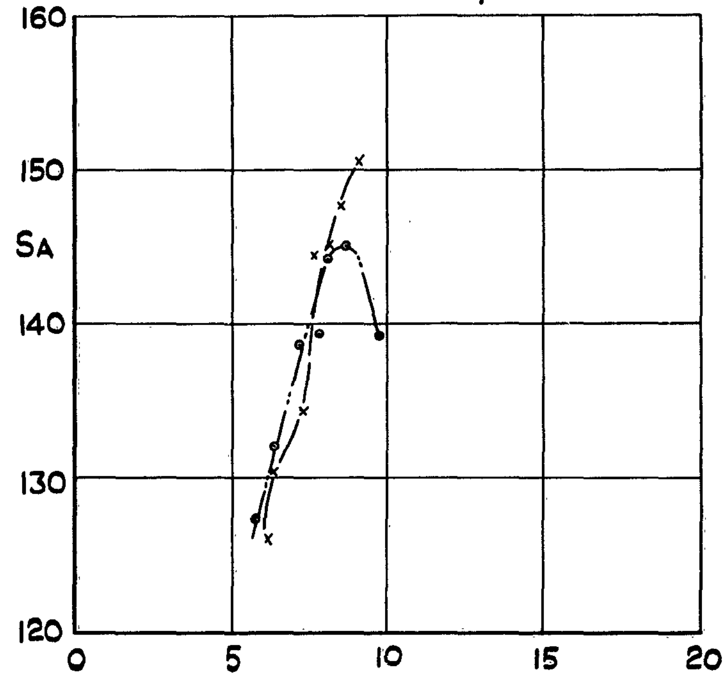


FIG. 33

FIG. 32 & 33 AIR SPECIFIC IMPULSE VERSUS AIR FUEL RATIO.

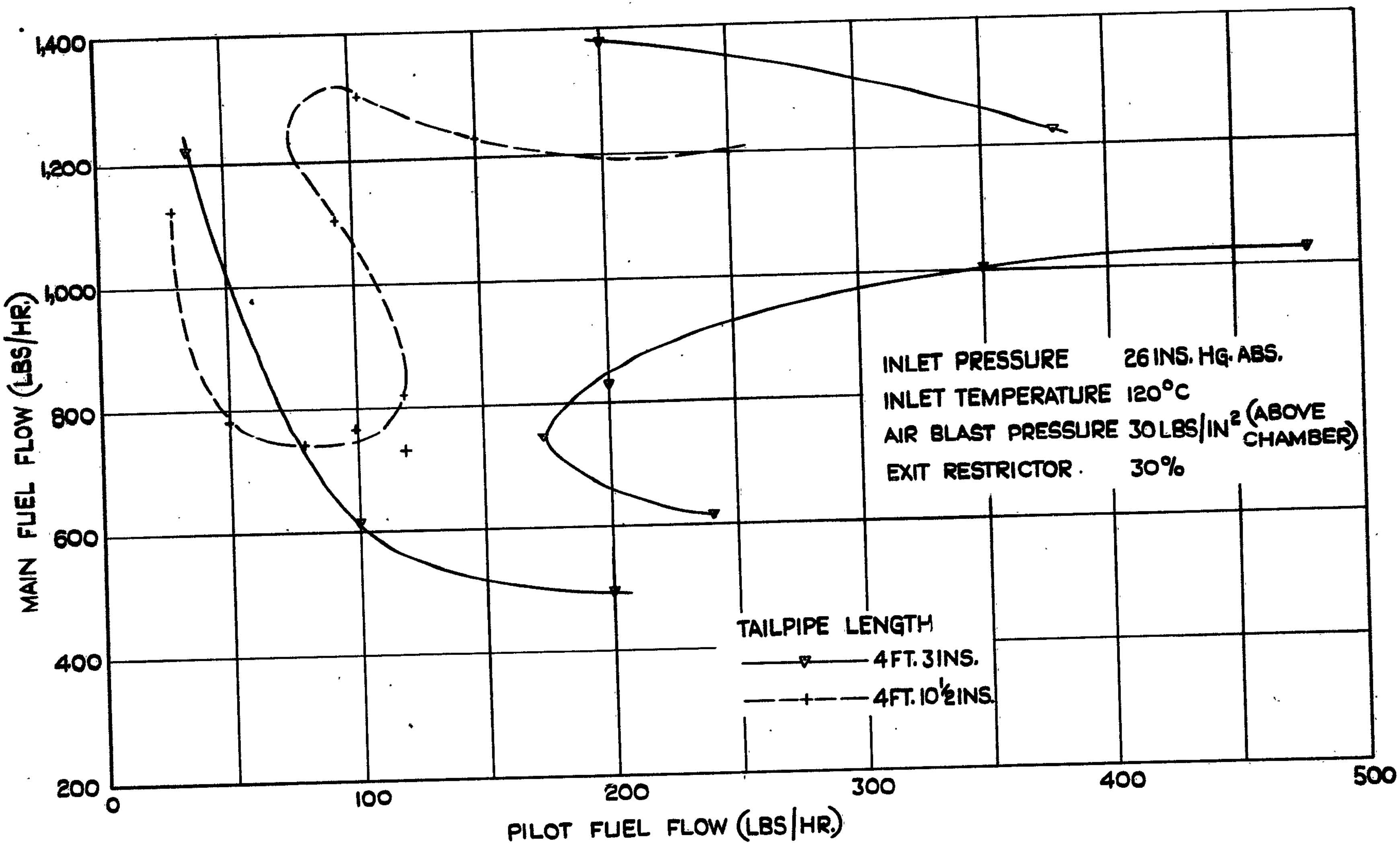


FIG. 34 STABILITY CURVES.

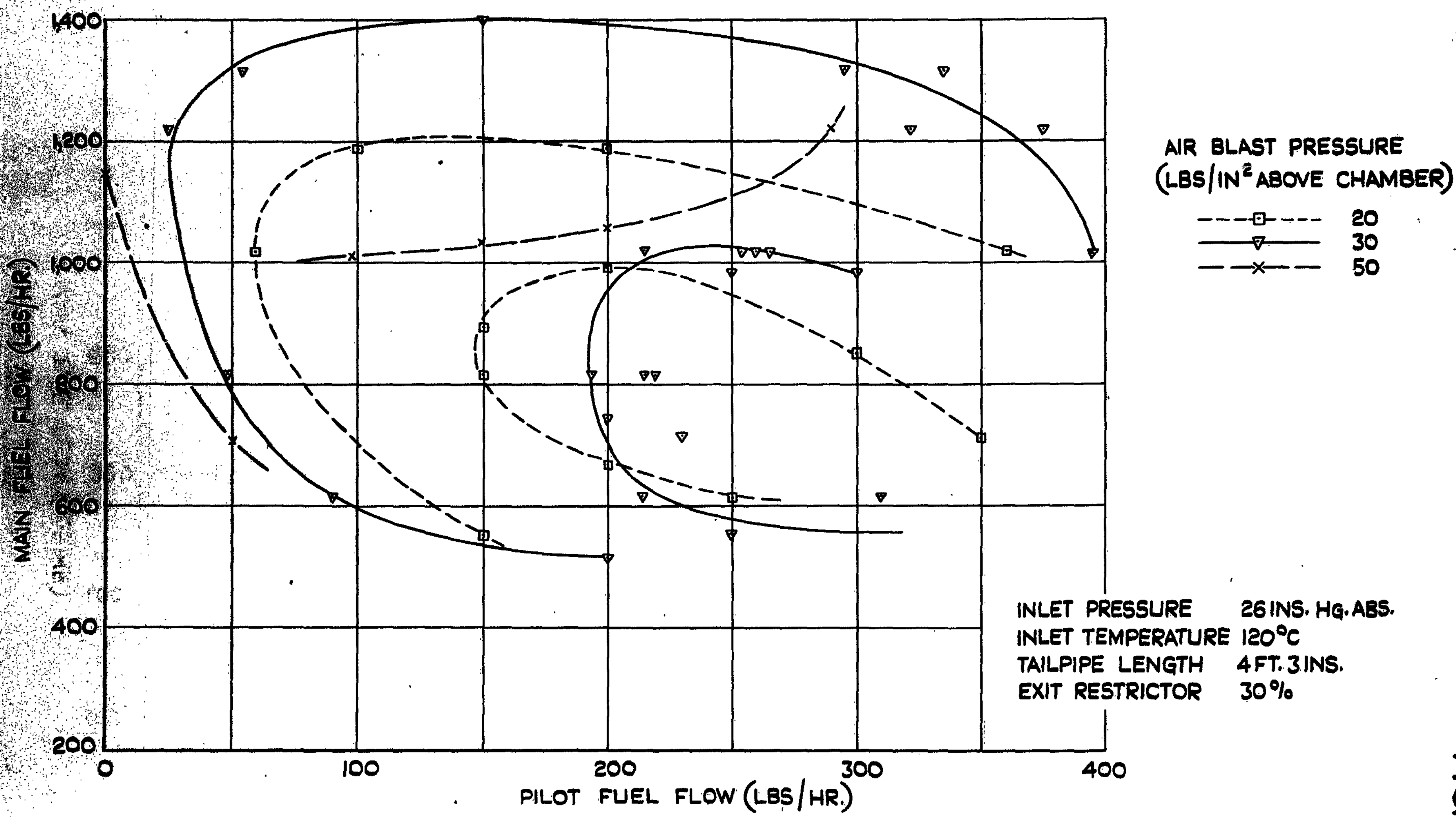


FIG. 35 STABILITY CURVES.

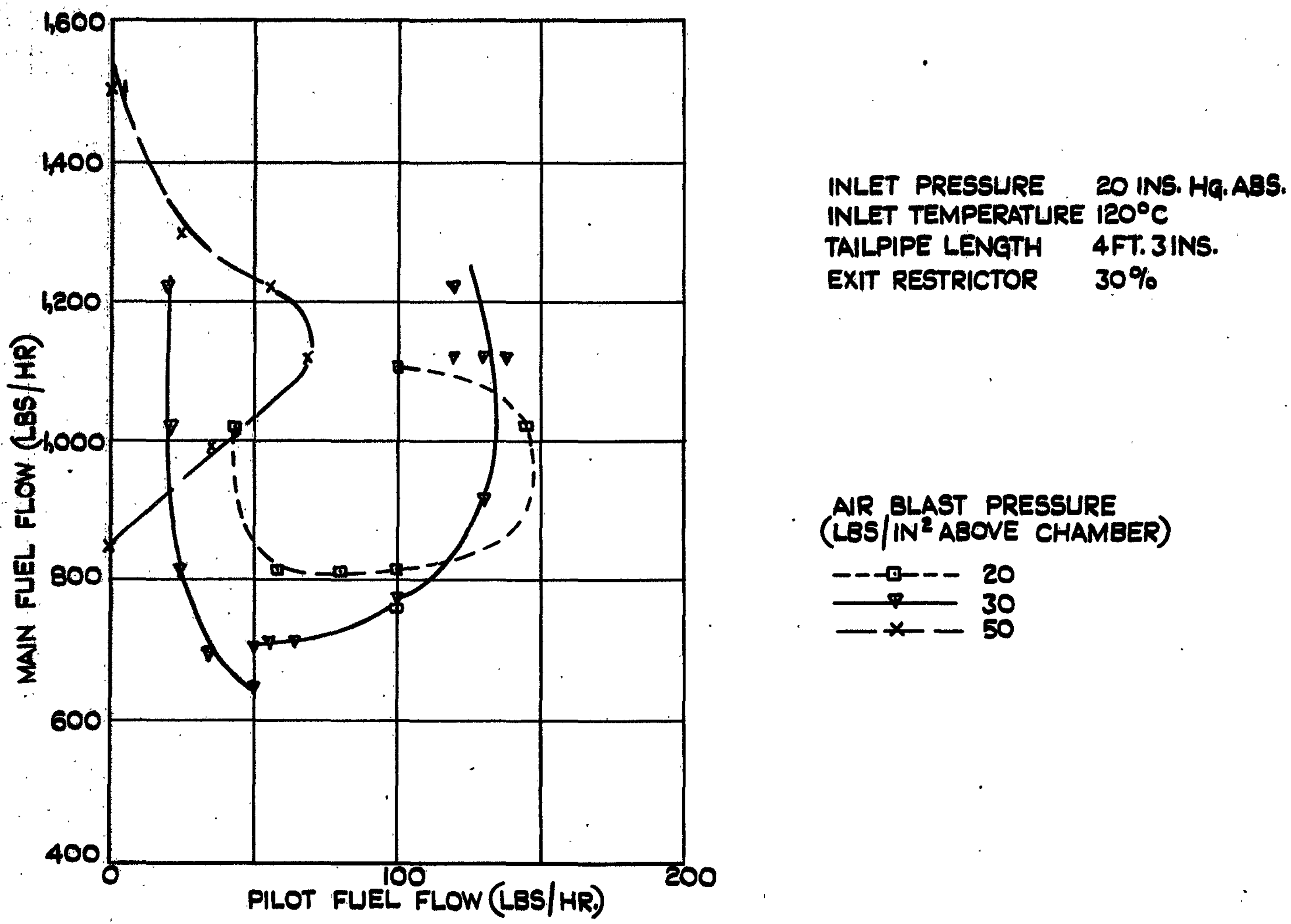


FIG36. STABILITY CURVES.

AIR BLAST PRESSURE
(LBS/IN² ABOVE CHAMBER)

- - -□- - - 20

——▽—— 30

INLET TEMPERATURE 120°C
TAILPIPE LENGTH 4FT. 3 INS.
EXIT RESTRICTOR 30%

INLET PRESSURE 26 INS. HG. ABS.
PILOT FUEL FLOW 100 LBS/HR.

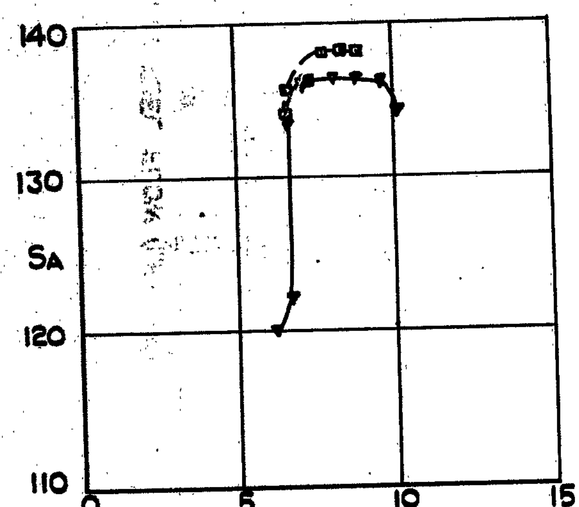


FIG 37.

INLET PRESSURE 20 INS. HG. ABS.
PILOT FUEL FLOW 75 LBS/HR.

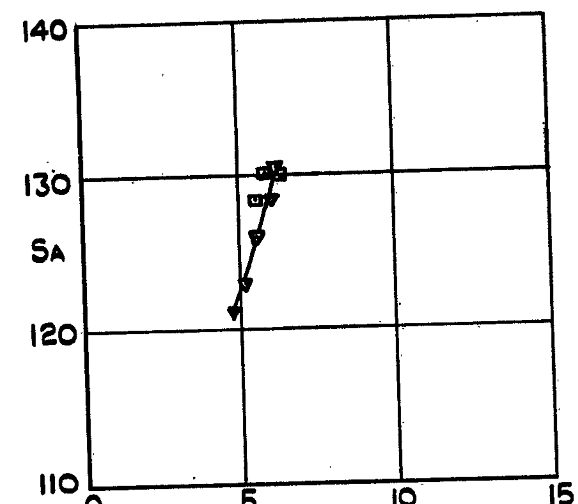


FIG 38.

FIG 37 & 38. AIR SPECIFIC IMPULSE VERSUS AIR FUEL RATIO.

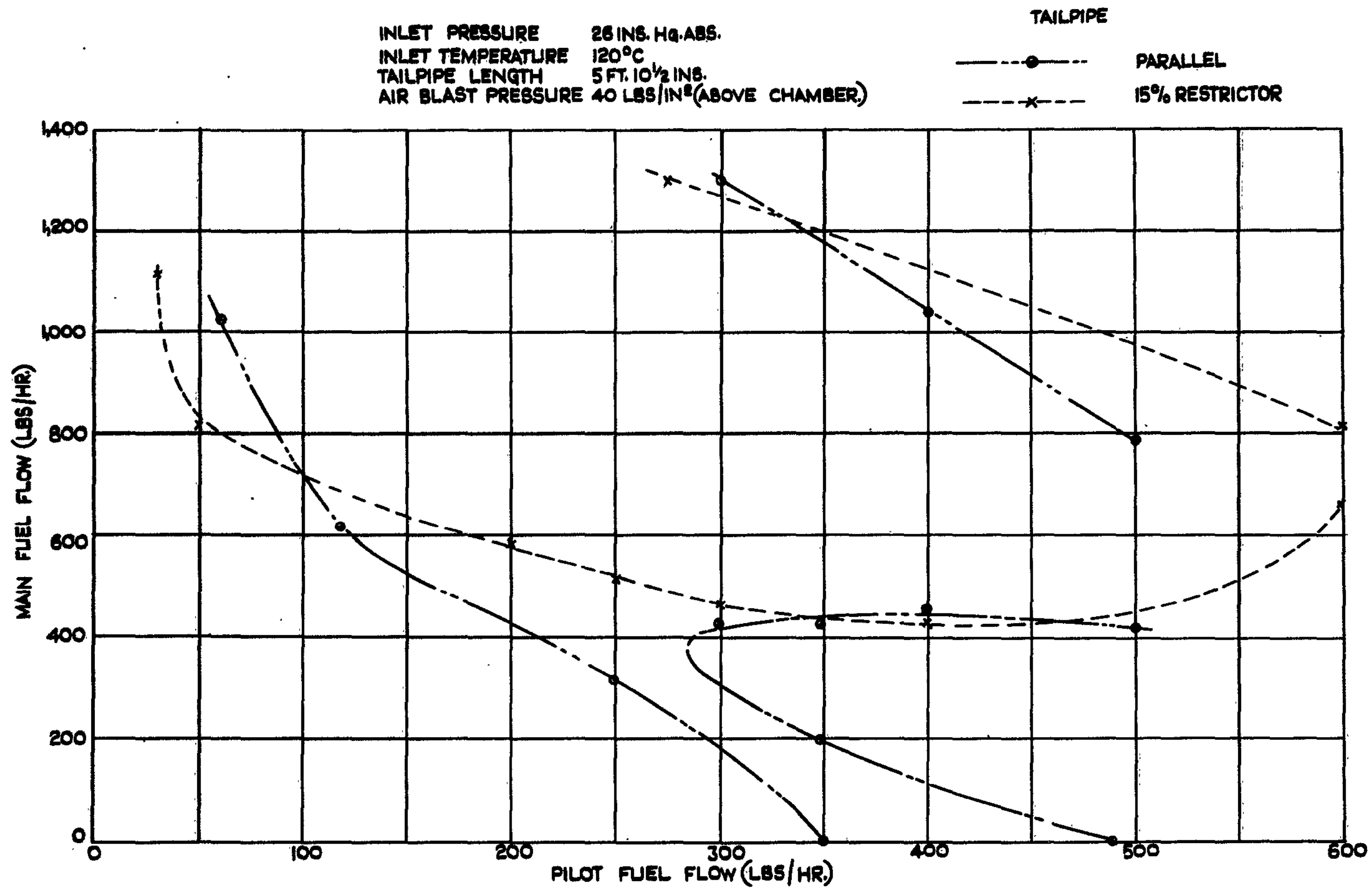


FIG 39. STABILITY CURVES.

FIG 40.

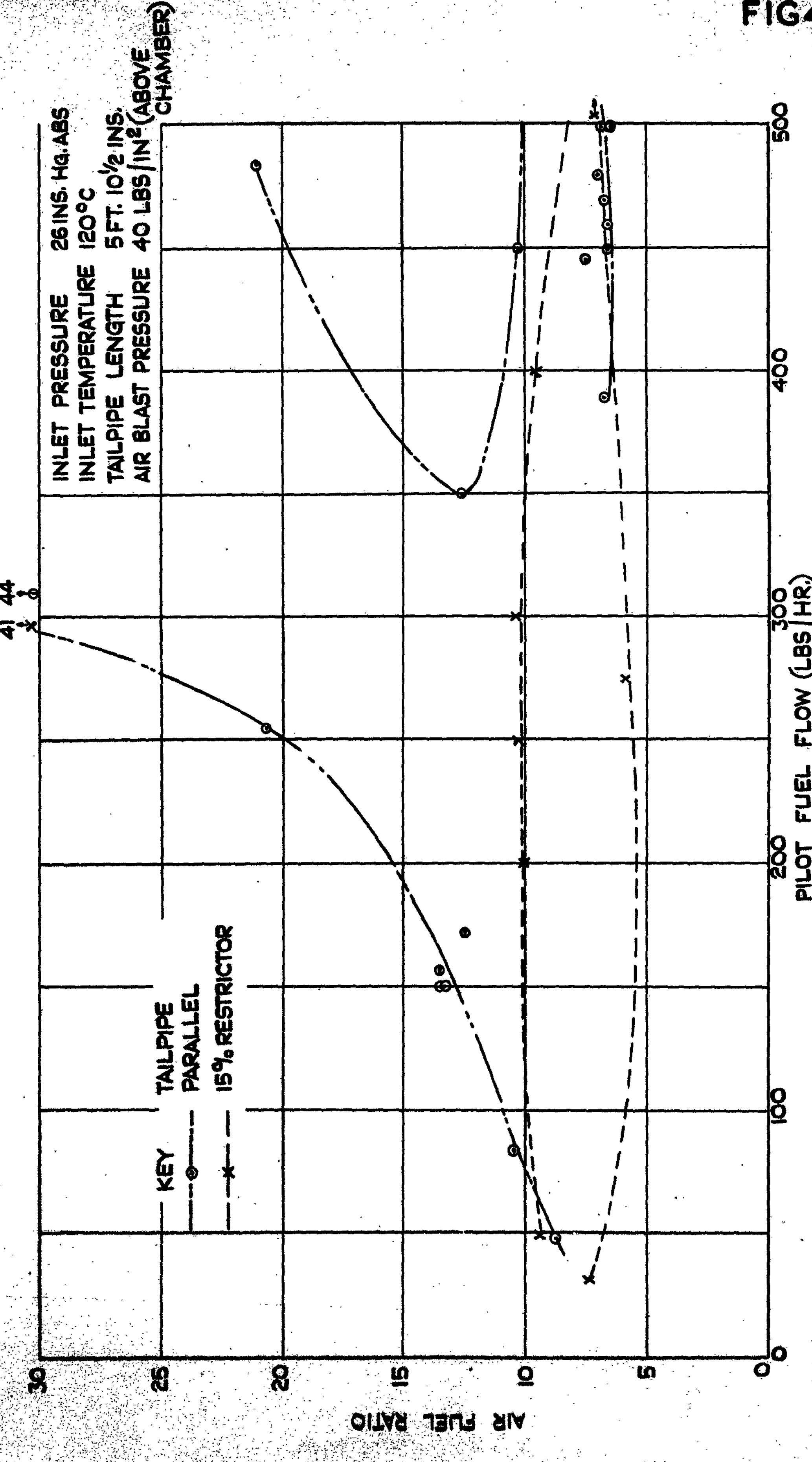


FIG 40 STABILITY CURVES.

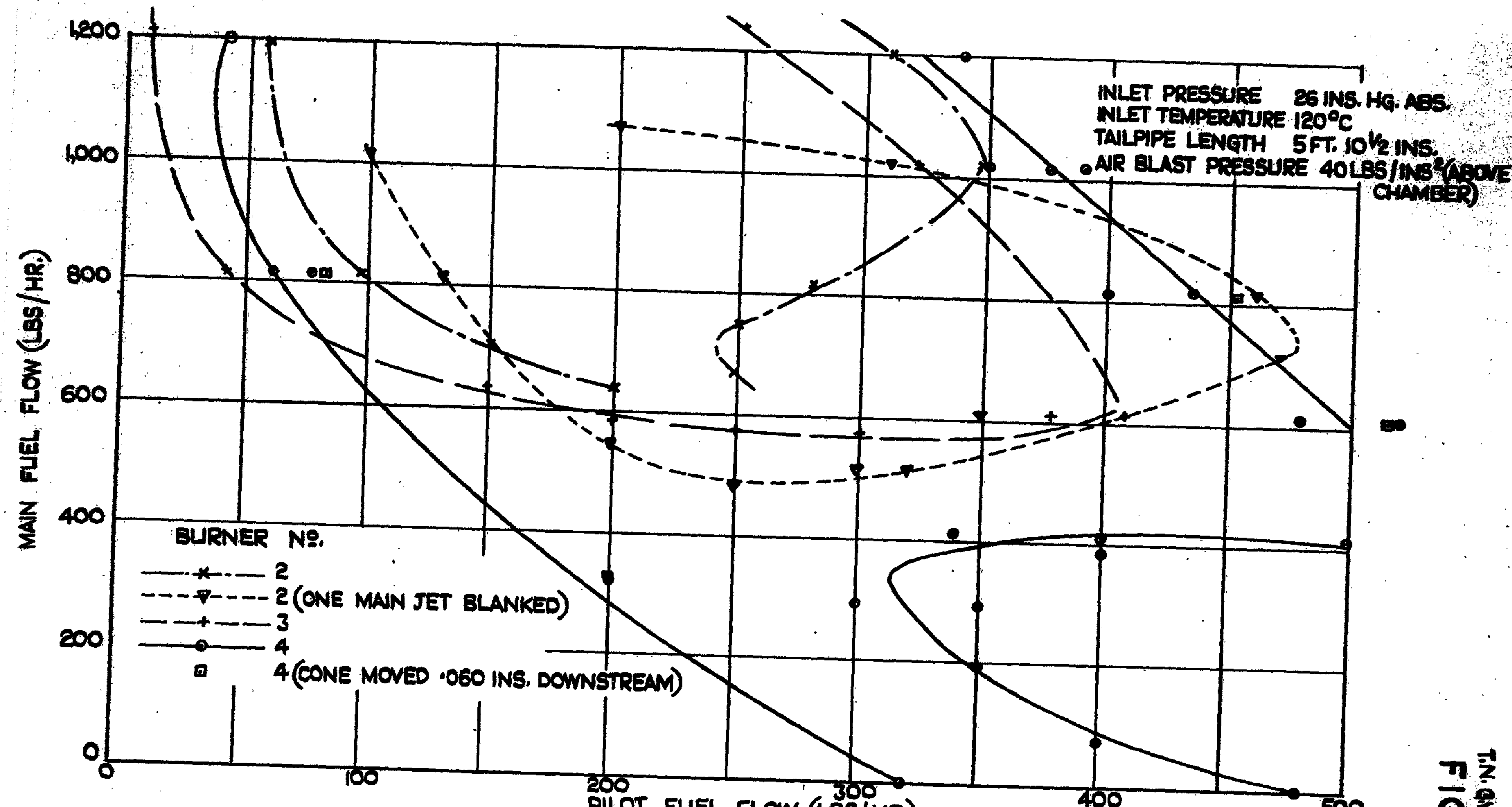


FIG 41. STABILITY CURVES.

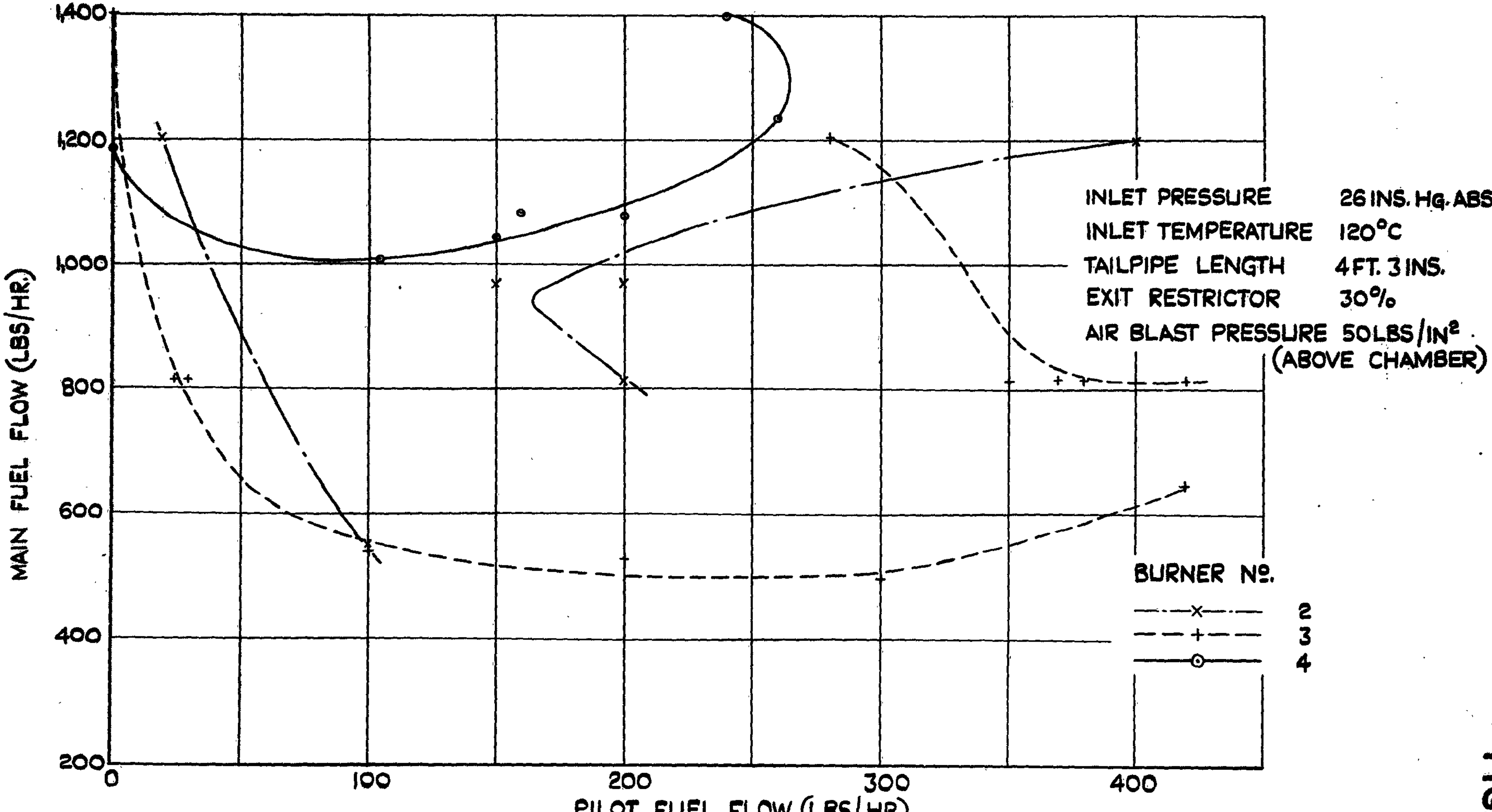


FIG. 42 STABILITY CURVES.

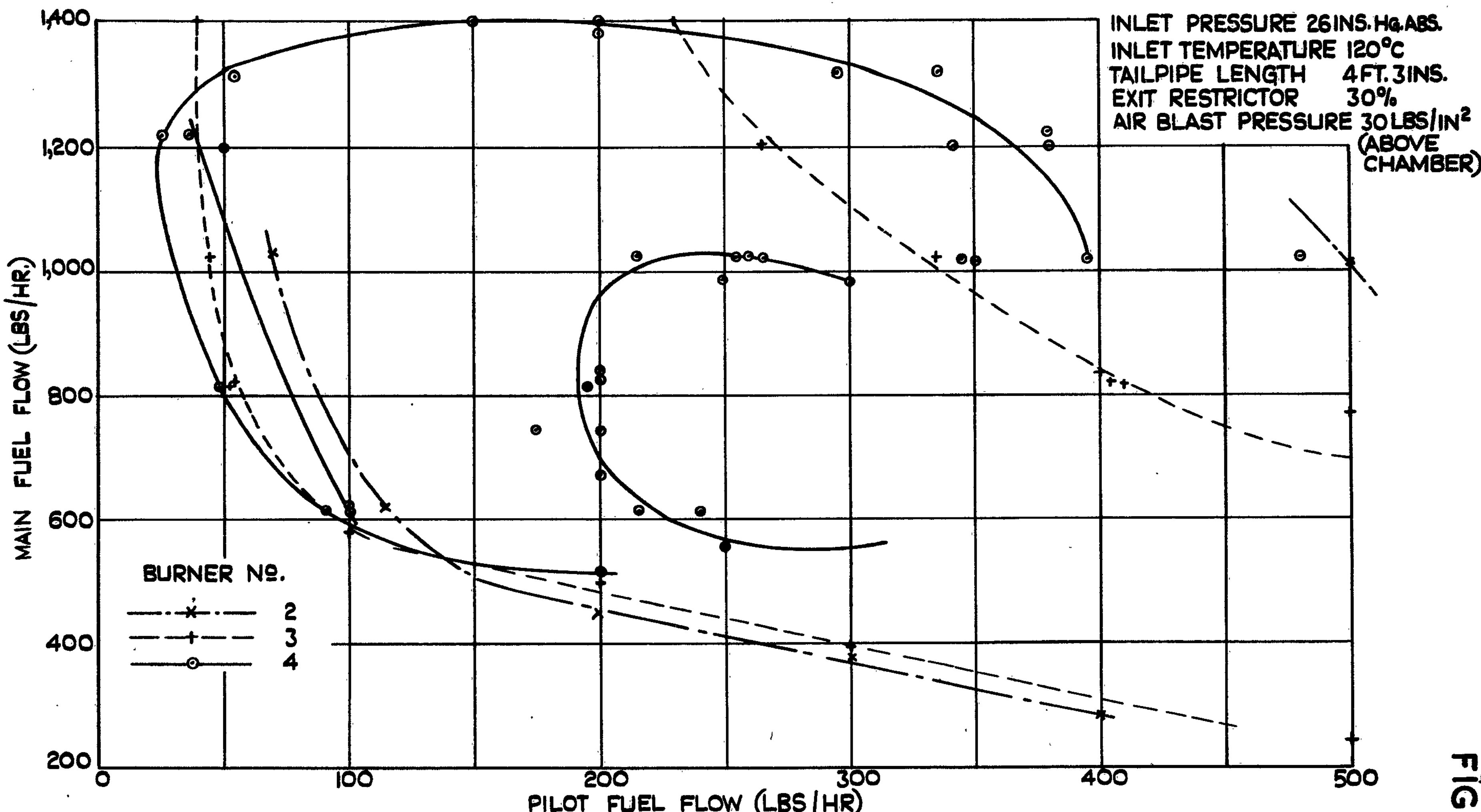


FIG 43. STABILITY CURVES.

[dstl]

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Record Summary: AVIA 6/17302
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